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CONTENTS

NOTICES

PROPELLERS FOR HIGH-SPEED AIRCRAFT
G. C. I. GARDINER AND P. BRETT

PRIMARY INSTABILITY OF A PANEL OF INTEGRAL CONSTUCTION WITH UNFLANGED STIFFENERS SYED YUSUFF

EFFECTS OF FUEL TYPE ON THE PERFORMANCE OF AERO GAS TURBINE COMBUSTION CHAMBERS, AND THE INFLUENCE OF DESIGN FEATURES J. G. SHARP

GUSTS AND THEIR MEASUREMENTS J. TAYLOR

HENRY PHILLIP FOLLAND—A TRIBUTE SIR ROY FEDDEN

TECHNICAL NOTES

The design of Static and Pitot Static Tubes for Subsonic Speeds—D. J. KETTLE. Viscous Effects on Flattened Pitot Tubes at Low Speeds—F. A. MACMILLAN. Definition of Specific Impulse—E. W. PRICE. A Method of rapidly Estimating Propeller Moment—F. R. PAYNE. Erratum for October.

THE LIBRARY REVIEWS REPORTS

INDEX TO VOLUME LVIII, JANUARY-DECEMBER 1954

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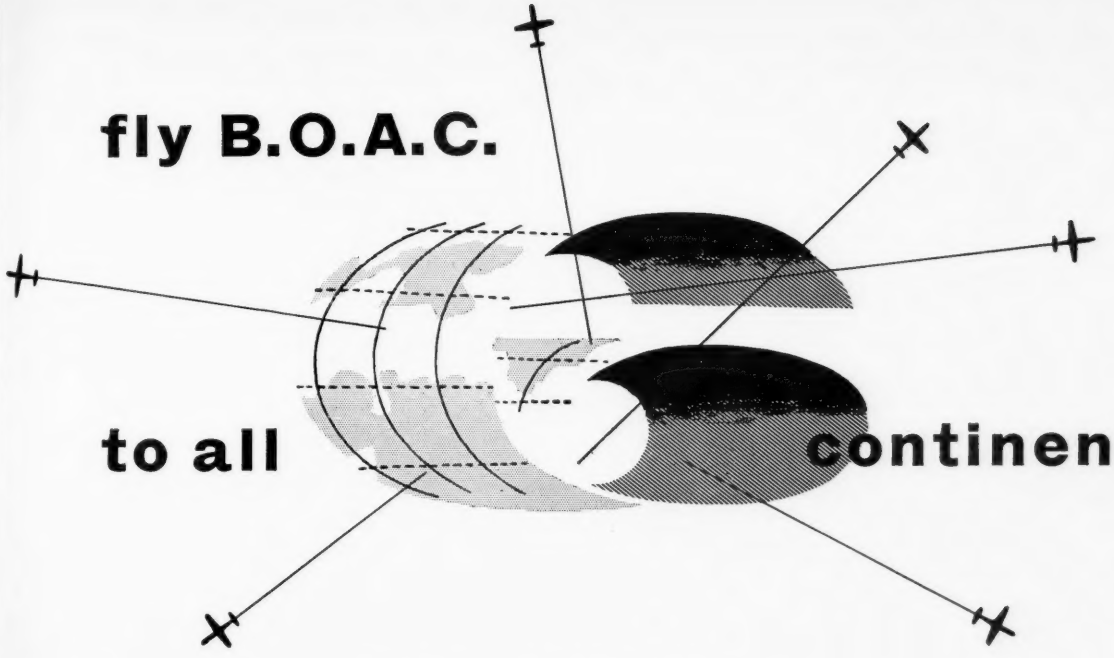

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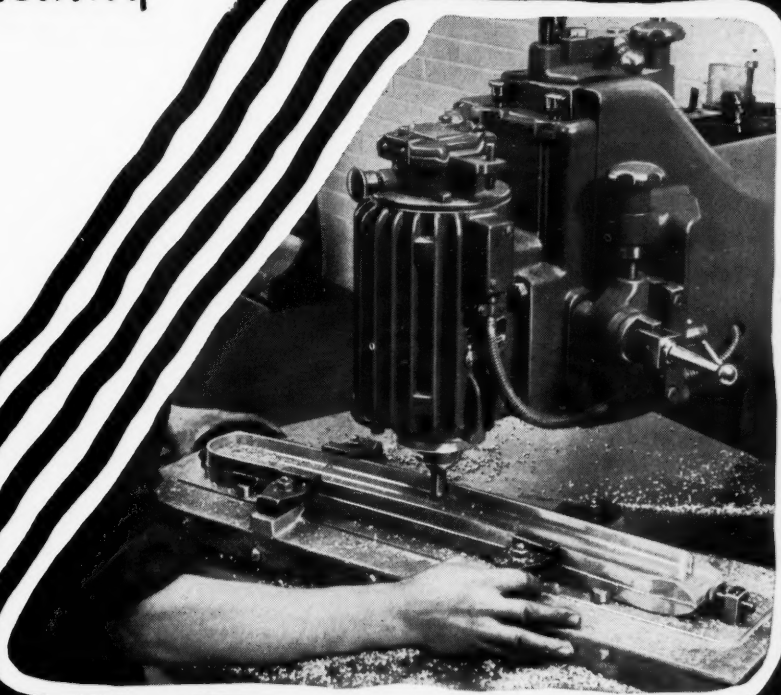

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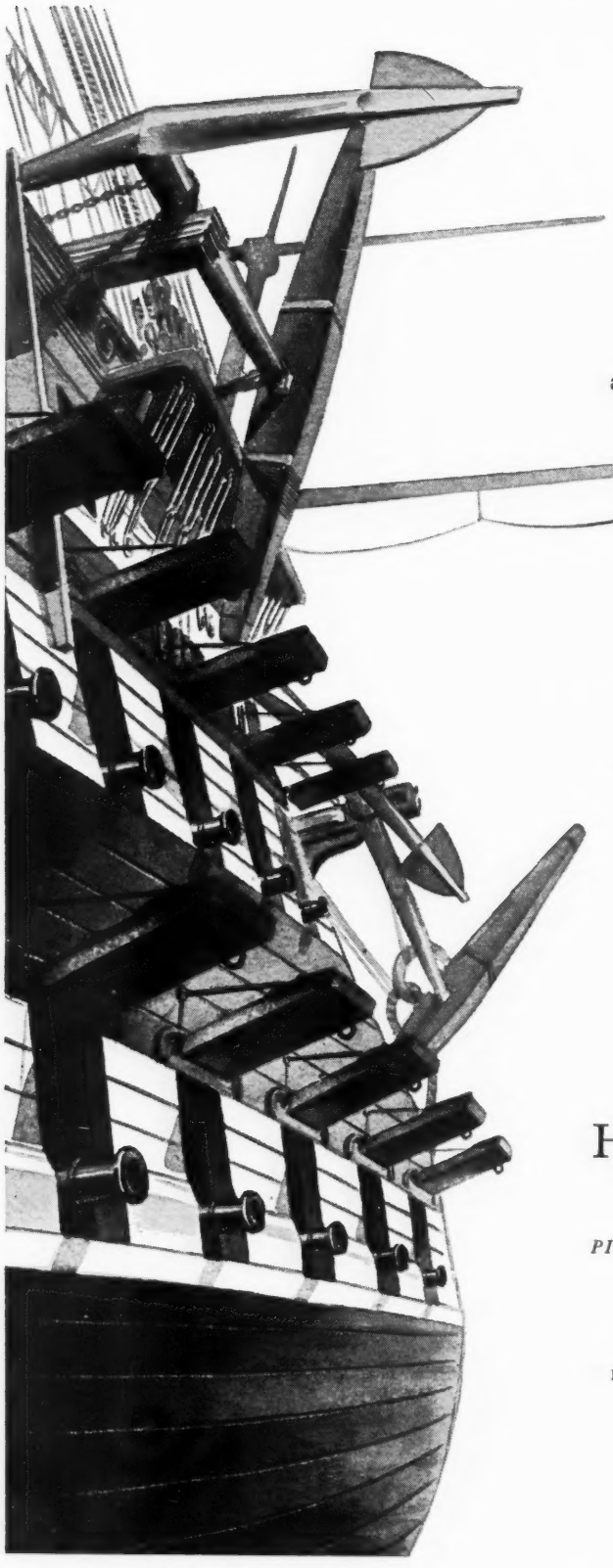

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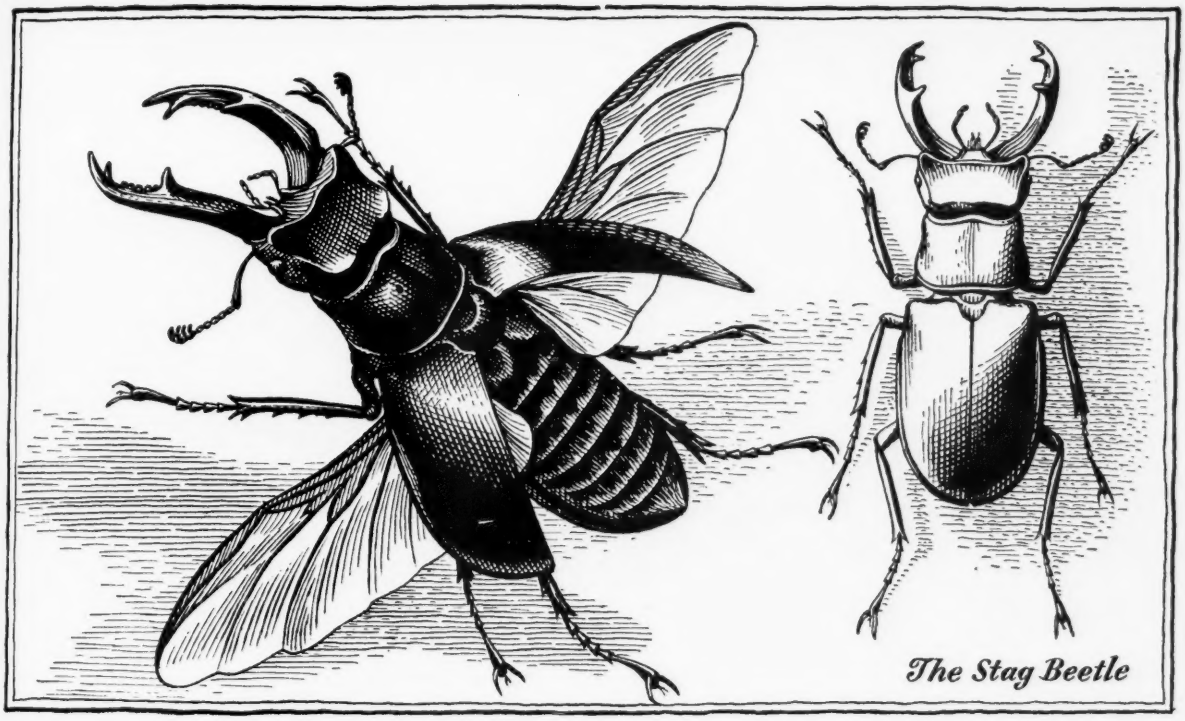
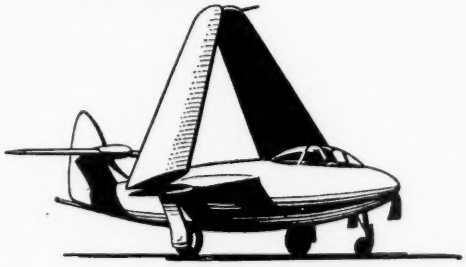


The Stag Beetle

FOLDING WINGS

Folding wings have been used by beetles since evolution was young. Man, in the carrier-based aircraft, has faced only recently the problem that Nature solved so long ago.



There are nearly as many different reasons for folding wings as there are different kinds of beetle—and beetles, with their 250,000 species, are the largest order in the animal kingdom. Their habits vary widely. Some no longer fly; some never did. Those that do have heavier bodies than any other flying insect, because of their thick plates of protective armour. (Some also have enormous jaws: those of the male stag-beetle illustrated may be for fighting other males during the mating season, or perhaps for scraping plant-shoots to get at the sap.)

This great weight demands large wings. Hence Nature's problem. For many beetles burrow into the earth; many fight; many find their food or their

safety in cracks in wood or chinks in stone. Unfolded wings would make all this impossible. And the beetle's wings are fragile. To keep himself airworthy he has to protect them under armoured covers. (These covers are actually his fore-wings, specially adapted for this special task.)

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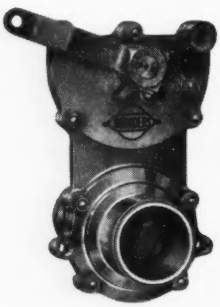

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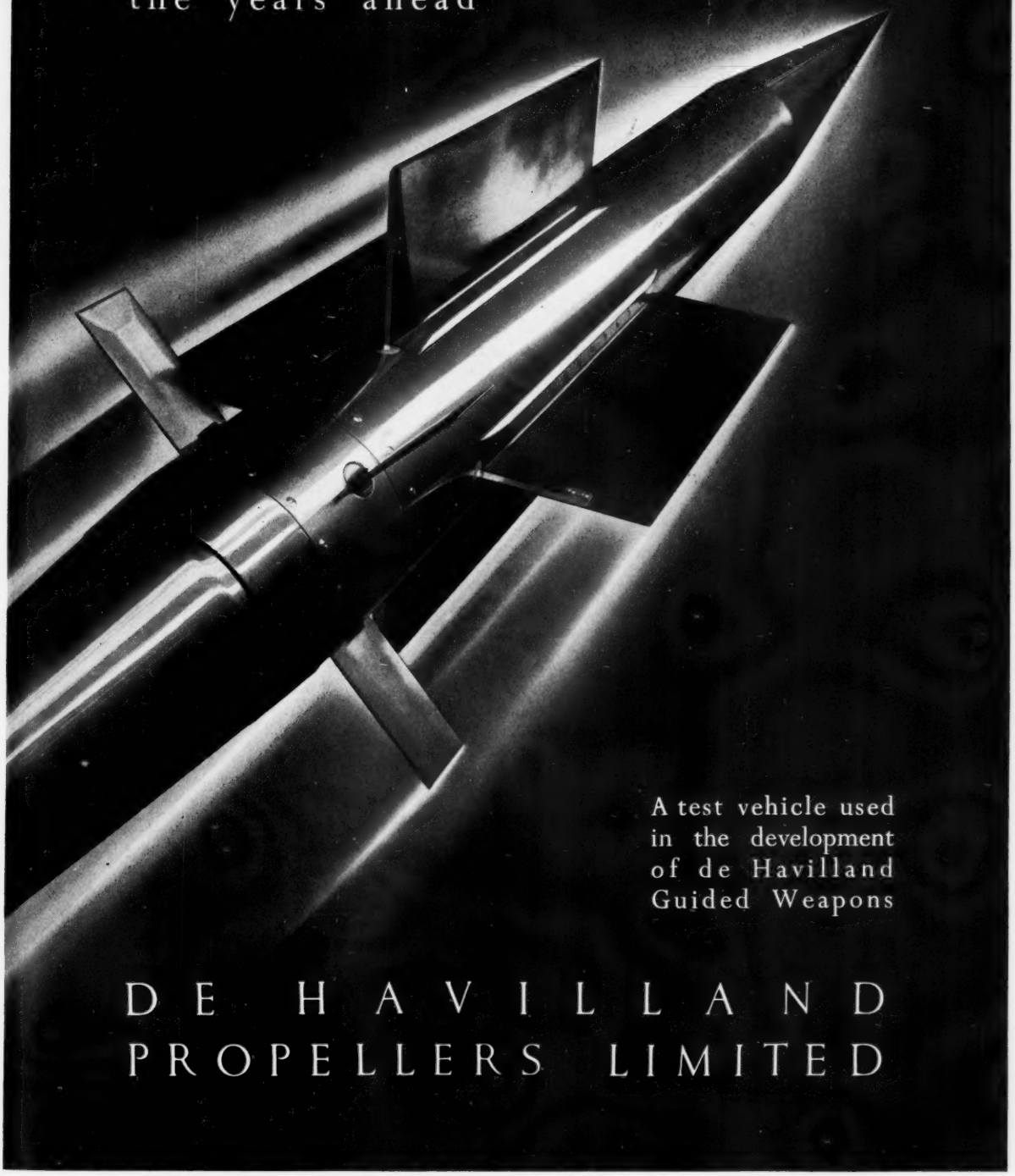

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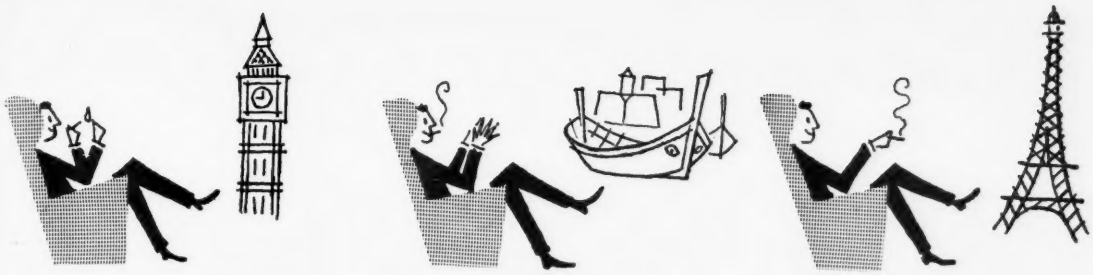

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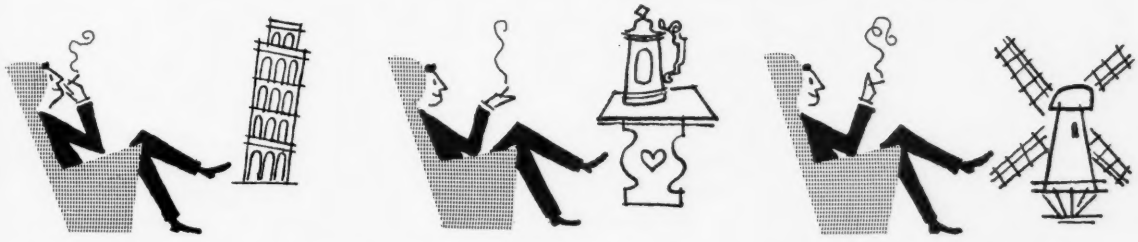

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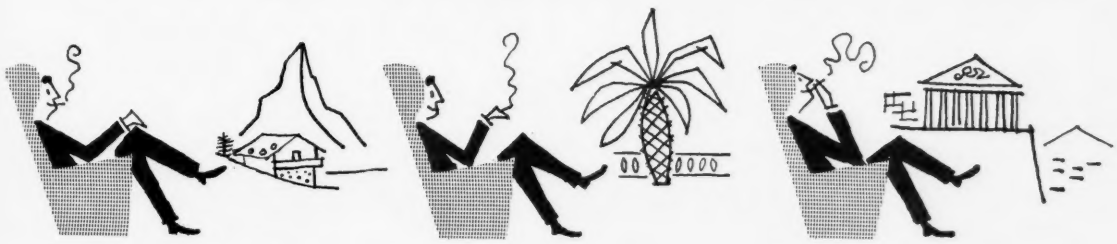

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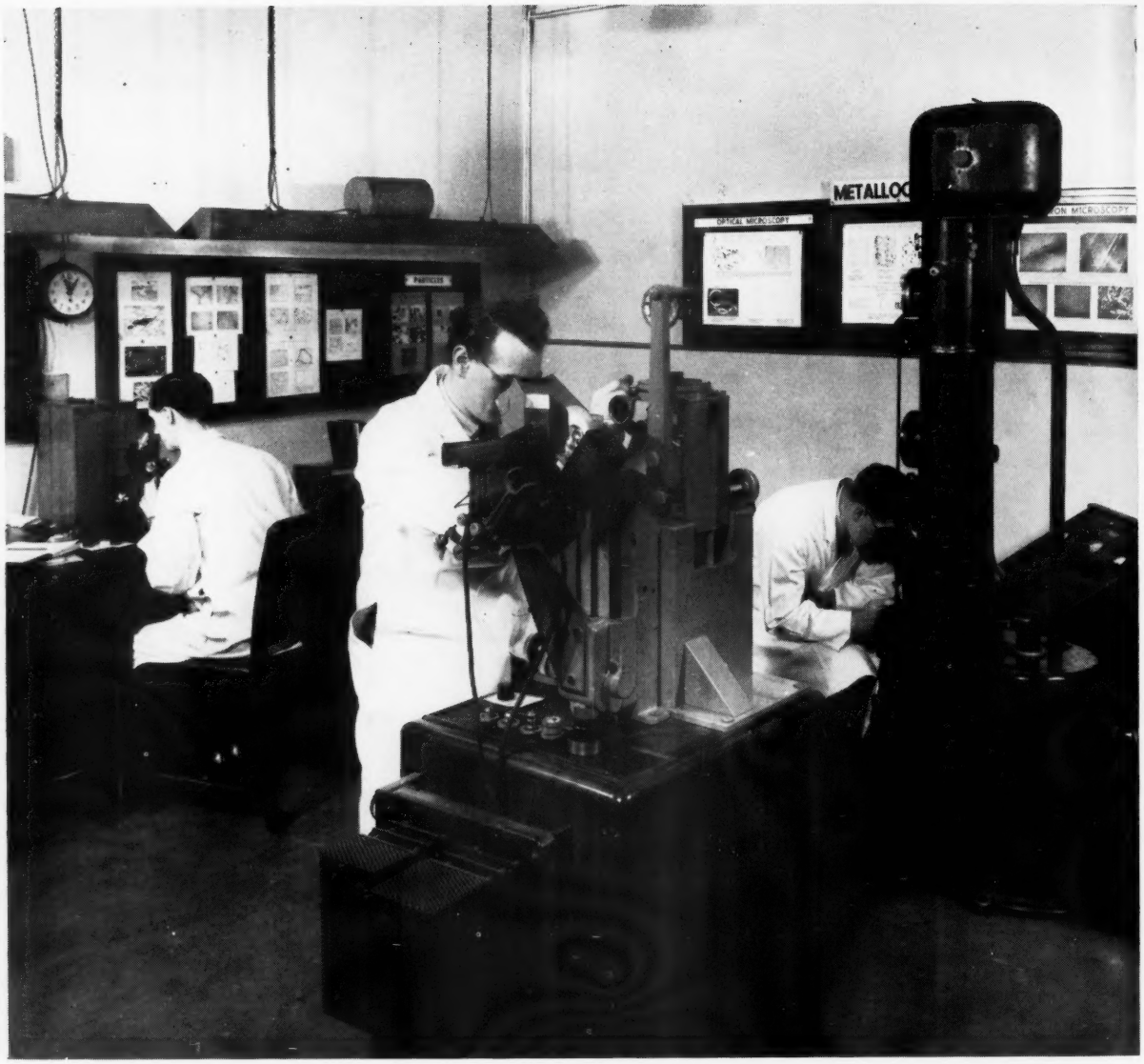

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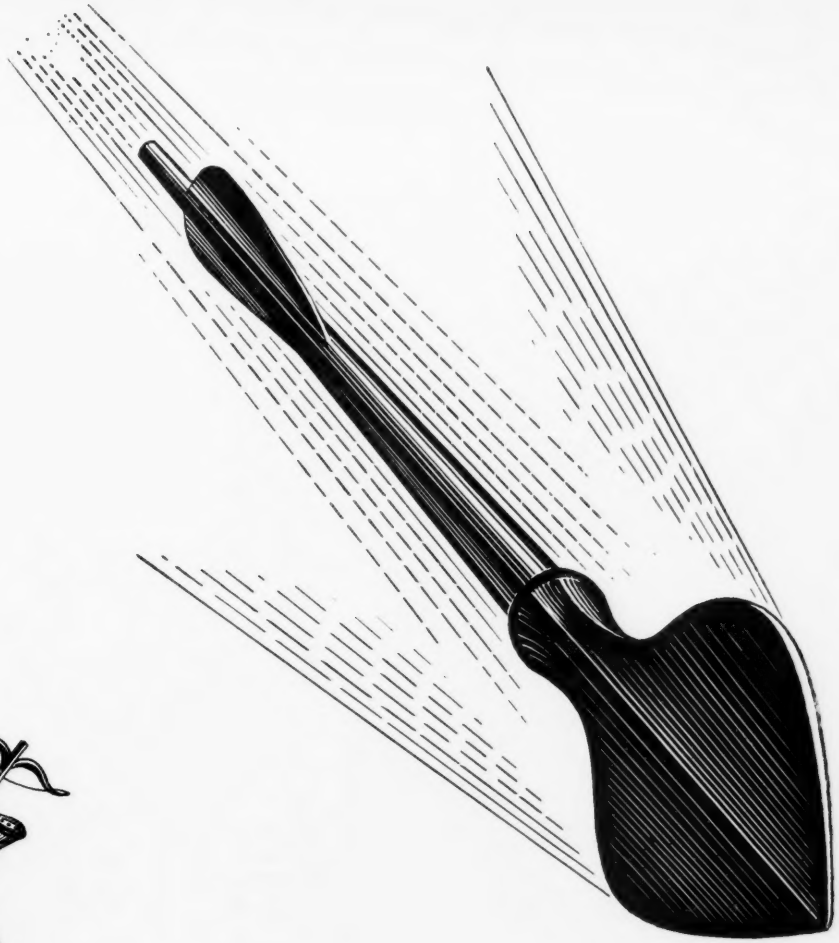

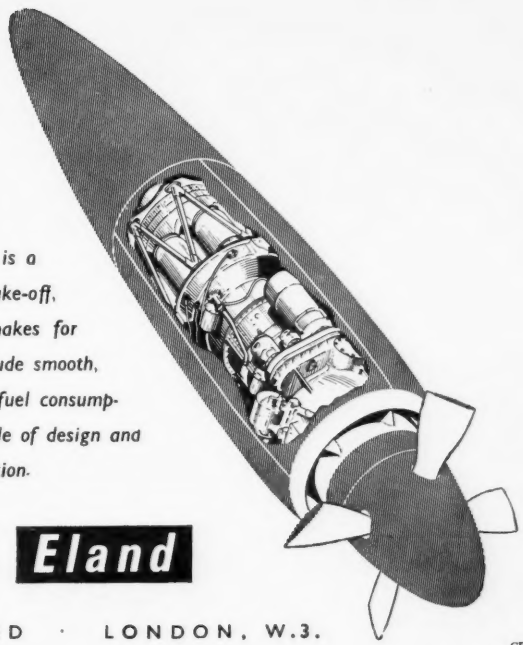

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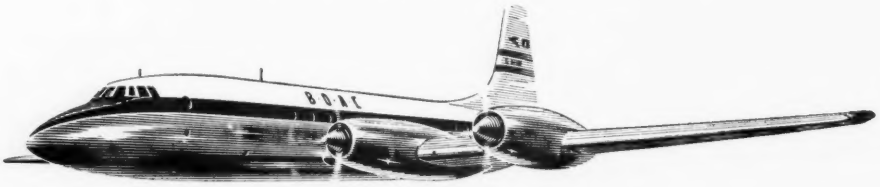

THE MEASURE OF efficiency of an airliner is its ability to make a profit when carrying fluctuating loads over varying distances. It is not competitive in the world market if it does so only under favourable route and load conditions. The economics depend to a very large extent on engine life, power, and above all, fuel consumption. Modern piston engines run for 1,000 hours between overhaul, give upwards of 3,000 hp and have a fuel consumption of $\frac{1}{2}$ lb per hp per hour, which in a four-engined airliner means about 1 mpg. Turbines can be expected to supersede piston engines only when they are conclusively superior on all counts.

Turbines are of two sorts—the turbojet which delivers its power in the form of an exhaust jet, and the turboprop which uses its power to drive a propeller. Both types of turbine can match the piston engine in longevity and outclass it in power. It is on fuel consumption that the two types of turbine differ. The consumption of the turbojet is about twice that of a comparable piston engine. This would not matter so much if the turbojet could do double the amount of work by flying twice as fast as the piston engine, but in the event an increase in cruising speed beyond about 400 mph does not bring about a commensurate gain in average journey speed. High fuel consumption is therefore a very real difficulty to the turbojet. In order to reduce its fuel consumption as much as possible, the jet aircraft must fly high; it is, in practice, locked inflexibly to a narrow band of altitudes in the fringes of the stratosphere. And the high wind velocities at these great altitudes make close timekeeping on east-west routes difficult on a year round basis.

In the turboprop the fuel consumption problem is largely mastered because this type of turbine, unlike the turbojet, makes use of the highly efficient propeller. Moreover, the turboprop airliner can cruise economically at any altitude between 15,000 and 35,000 feet and thus, by flying at the appropriate level, can minimise the effect of headwinds and take advantage of tailwinds. This flexibility of operation is a feature of the Britannia airliner which, now in production, is powered with Bristol Proteus turboprop engines. The Proteus 755 develops 4,150 hp and is thus a good deal more powerful than current piston engines. Its consumption is some 10 per cent greater but this is more than offset by using a cheaper fuel.

A pointer to the importance of fuel consumption is that fuel costs amount to the largest single item of operational expenditure in the average airline. Thus the air transport industry's long-range vehicles capable of carrying big payloads at peak periods must also have a fuel consumption which enables them to carry economically the smaller payloads of the off-season. Piston engines do this now and airlines will buy the turbines that can lift bigger loads faster and cheaper. There is a vast world investment in the piston engine and it will only be worth staking the future on a new prime mover that is markedly superior all round. The true civil and military workhorse engine is the turboprop.

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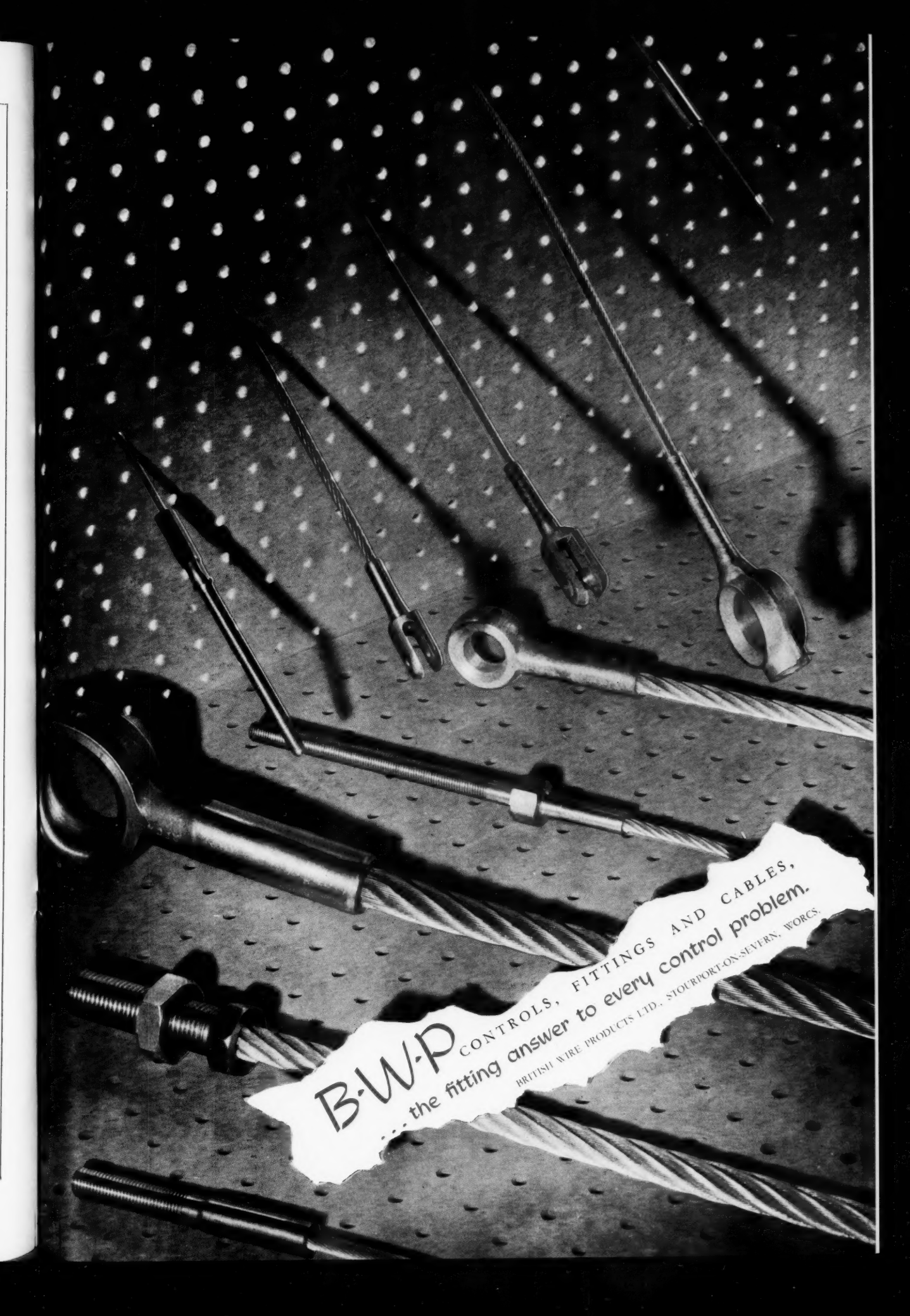
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VOLUME 58 DECEMBER 1954 NUMBER 528

CONTENTS

PAGE

Notices LIX

The Tenth British Commonwealth and Empire Lecture—Christmas 1954—Library—Honours and Awards to Members—Graduates' and Students' Section—Acknowledgments—News of Members—Diary—Elections—Elliott Memorial Prize—Journal Binding—Annual Subscriptions—Changes of Address.

Propellers for High-Speed Aircraft G. C. I. GARDINER AND P. BRETT 799

Primary Instability of a Panel of Integral Construction with Unflanged Stiffeners SYED YUSUFF 808

Effects of Fuel Type on the Performance of Aero Gas Turbine Combustion Chambers, and the Influence of Design Features J. G. SHARP 813

Gusts and Their Measurement J. TAYLOR 826

Henry Phillip Folland—A Tribute SIR ROY FEDDEN 833

Technical Notes 835

The Design of Static and Pitot Static Tubes for Subsonic Speeds—D. J. KETTLE. Viscous Effects on Flattened Pitot Tubes at Low Speeds—F. A. MACMILLAN. Definition of Specific Impulse—E. W. PRICE. A Method of Rapidly Estimating Propeller Moment—P. R. PAYNE. Erratum for October.

The Library 841

REVIEWS: Aerodynamics—Memoires sur la Mecanique des Fluides—Titanium and Titanium Alloys—Strategy for the West—Theoretical Elasticity—Mach One—Fleet Air Arm—Electrical Ignition Equipment—Jusqu' au Bout sur nos Messerschmitt—The Fluid Dynamics and Thermodynamics of Compressible Fluid Flow—The Royal Air Force, Vol. III: The Fight is Won—Flight Handbook—Aircraft for All—Rendez-Vous 127—To Perish Never—Neville Duke's Book of Flying—"Tiger" Squadron—Sound Barrier.

ADDITIONS TO THE LIBRARY. REPORTS.

Index to Volume LVIII, January-December 1954

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Chairman: A. E. BINGHAM, F.R.Ae.S.
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President: Air Vice-Marshal Sir CONRAD COLLIER, K.C.B., [C.B.E.
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YEOVIL
Hon. Secretary: L. A. LANSDOWN, A.F.R.Ae.S.,
Westland Aircraft Ltd., Yeovil.

NOTICES

An annual sum of £250 is available for premium awards for papers, including Technical Notes, published in the Journal. Members and non-members of the Society are invited to submit papers on any aspect of aeronautics

Christmas 1954

The President, Sir Sydney Camm, the Council and the Staff of the Society wish all members at home and overseas, a Very Happy Christmas.

The Library and Offices of the Society will be closed for the Christmas Holiday from 5 p.m. on Friday 24th December to 9 a.m. on Wednesday 29th December.

Library

The Library will be closed on Monday, Tuesday and Wednesday 20th, 21st and 22nd December.

Honours and Awards to Members

Wing Commander T. R. Cave-Brown-Cave (*Fellow*) has been awarded a prize by the Royal Society of Arts in their Bicentenary Competition for forecasts of practical aspects of life on earth in the year 2,000 A.D. He submitted a scheme for Rooftop Roadways.

Mr. G. H. Dowty (Past President, *Fellow*) has been elected an Honorary Fellow of the Canadian Aeronautical Institute.

Mr. Dowty is also to receive the Honorary Freedom of the Borough of Cheltenham, in recognition of the outstanding and distinguished Services rendered by him in the field of industry and to the progress and life of the town over many years.

Captain A. M. A. Majendie (*Associate Fellow*) has been awarded the Gold Medal of the Institute of Navigation for his contributions to the navigation of jet aircraft.

The Fédération Aéronautique Internationale has awarded a De La Vaux Medal to Squadron Leader N. F. Duke (*Associate*). These medals are awarded to holders of recognised world records gained during the year.

The Fédération Aéronautique Internationale has also awarded Paul Tissandier Diplomas to Sir Sydney Camm (President, *Fellow*), Mr. A. G. Elliott (Vice-President, *Fellow*), Mr. W. E. W. Petter (*Fellow*) and Mr. J. Smith (*Fellow*). These diplomas are awarded to those who have "by their influence, work, initiative and devotion, or in some other way, served the cause of aviation in general especially private and sporting flying."

Graduates' and Students' Section

A visit has been arranged to the Guinness Brewery at Park Royal, London, for Saturday 19th February 1955, at 2.15 p.m. Applications for this visit should be made to the Hon. Visits Secretary, Mr. P. D. Stewart, 217 High Road, East Finchley, London, N.2.

Acknowledgments

The Council wish to acknowledge with sincere thanks the gift of valuable books and pictures from Sir John Buchanan, C.B.E., Past President and *Fellow*.

They also acknowledge with thanks the return of back numbers of The Journal from Captain W. Baillie, *Associate Fellow;* and Mrs. Elsie Ross (widow of the late Major A. A. Ross, *Fellow*).

The Tenth British Commonwealth and Empire Lecture

The Council have pleasure in announcing that His Royal Highness the Duke of Edinburgh, K.G., K.T., will deliver the Tenth British Commonwealth and Empire Lecture on Thursday 16th December 1954 at 5.30 p.m. in the Assembly Hall, Church House, Great Smith Street, Westminster, S.W.1.

Admission to the Lecture will be by ticket only and all ticket holders must be in their seats by 5.15 p.m.

News of Members

Ivor Bowen (*Fellow*) has joined the General Precision Equipment Corporation of the U.S.A. as British Empire Representative resident in London.

D. S. Carton (*Associate*) who has recently returned from Pakistan, has taken up a post as Demonstrator in the Department of Aircraft Propulsion at the College of Aeronautics, Cranfield.

Col. E. Duncan-Smith (*Associate Fellow*) has been appointed radio advisor for the Mid-East region with special reference to civil aviation communication and navigational aid extensions.

Z. Funt (*Associate Fellow*) has left this country to take up a post as principal of the Technical High School, Belize, British Honduras.

A. V. Garnett (*Associate Fellow*) has been appointed a Flight Test Engineer with British European Airways.

W. A. Hibbert (*Associate Fellow*) has taken up an appointment as Inspector in Charge, A.I.D., at Blackburn and General Aircraft Ltd., Brough, Yorkshire.

H. T. Hill (*Associate Fellow*) has been appointed Assistant Director, Workshops, at the Royal Aircraft Establishment, Farnborough.

J. W. King (*Associate*) is now employed as Works Manager with Rediweld Ltd., of Crawley, Sussex.

Squadron Leader H. A. Krasinski (*Associate Fellow*) has taken up a teaching appointment in the Mechanical Engineering Department of the Coventry Technical College.

Wing Cdr. L. C. N. Penney (*Associate*) has been appointed to a R.A.F./U.S.A.F. Exchange Post for a two-year tour of duty.

D. Simpson (*Graduate*) has been released from the Royal Air Force to take up an appointment as a Test Pilot with Hawker Aircraft Ltd.

S. Spencer (*Associate Fellow*) has been appointed Technical Superintendent at No. 27 Maintenance Unit, R.A.F.

C. K. Turner-Hughes (*Associate Fellow*) has been appointed Commercial Manager of the Aircraft Electrical Division of The Plessey Co. Ltd.

H. M. Whitcombe (*Associate Fellow*) has been appointed an additional director of R. B. Pullin & Co. Ltd.

Group Captain D. W. Williams (*Associate Fellow*) has taken over Command of Royal Air Force, Melksham, Wiltshire.

Diary

LONDON.

9th **December**

SECTION LECTURE.—Problems of Structural Design. D. James. 4 Hamilton Place, W.1. 7 p.m.

16th December

Tenth British Commonwealth and Empire Lecture.—H.R.H. The Duke of Edinburgh.—Assembly Hall of Church House, Westminster. 5.30 p.m. Admission by ticket only. See separate notice.

21st December

SECTION LECTURE.—Servo Tab Controls. Dr. W. J. Strang. 4 Hamilton Place, W.1. 7 p.m.

4th **January** 1955

SECTION LECTURE.—Recent Advances in the Knowledge of Transonic Air Flow. C. H. E. Warren. 4 Hamilton Place, W.1. 7 p.m.

6th January

MAIN LECTURE.—Lecture to Young People. P. G. Masefield. The Institution of Mechanical Engineers, 1 Birdcage Walk, S.W.1. **3 p.m.** (Tea 4.30 p.m.)

18th January

SECTION LECTURE.—Manufacture of Integral Structures. Dr. E. G. West. 4 Hamilton Place, W.1. 7 p.m.

27th January

SECTION LECTURE.—Dynamic Problems of Interplanetary Flight. D. F. Lawden. 4 Hamilton Place, W.1. 7 p.m.

BRANCHES

6th **December**

Halton.—Some Aspects of Aircraft Design. Squadron Leader R. E. W. Harland. Branch Hut, R.A.F., Halton. 6.45 p.m.

Henlow.—Film Evening. Building No. 62, R.A.F. Technical College, Henlow. 7.30 p.m.

7th December

Bristol.—Living Machines. W. Grey Walter. Conference Room, Filton House, Bristol Aeroplane Co. 6 p.m.

8th December

Brough.—Fatigue: The Metallic Death-Watch Beetle. D. C. Smith and E. W. C. Wilkins. Lecture Hall, Yorkshire Electricity Board, Hull. 7.30 p.m.

Chester.—Compound Diesel Engines for Aircraft. E. E. Chatterton. Grosvenor Hotel, Chester. 7.30 p.m.

Weybridge.—From Subsonic to Supersonic. Dr. D. W. Holder. Vickers-Armstrongs Ltd., Weybridge. 6 p.m.

9th December

Cheltenham.—(Joint Lecture with the Society of Instrument Technology). Packing of Precision Equipment. S. C. Schuler. St. Mary's College, Cheltenham. 7.30 p.m.

Isle of Wight.—Annual General Meeting and Film. Saunders-Roe Club House, Church Path, E. Cowes. 6.30 p.m.

Yeovil.—High Speed Air Tunnels. R. Hills. Park School, Park Road (off Princes Street), Yeovil. 7.30 p.m.

10th December

Birmingham.—Aircraft Electrics. H. E. West. Birmingham Chamber of Commerce, New Street, Birmingham. 7.30 p.m.

Bristol.—Christmas Ball. Royal Hotel, Bristol. 8 p.m.

Preston.—Annual Dance. Imperial Hotel, Blackpool.

11th December

Cheltenham.—Buffet Dance. Queen's Hotel.

14th December

Belfast.—Debate: Modern Aircraft are Unnecessarily Complicated. Kerr Room, Kensington Hotel. 7 p.m.

15th December

Coventry.—Film Evening. Wine Lodge, Coventry. 7.30 p.m.

Southampton.—Some Recent Developments in High Speed Aircraft. Handel Davies. Institute of Education, University of Southampton. 7 p.m.

17th December

Weybridge.—Annual Dance.

3rd **January 1955**

Belfast.—Model Making. T. Gowan. Reception Room, Kensington Hotel, Belfast. 7 p.m.

5th January

Brough.—The Domain of the Helicopter. Raoul Hafner. Lecture Hall, Yorkshire Electricity Board, Hull. 7.30 p.m.

Chester.—Aircraft Wheels and Brakes, Development Testing. P. W. Dryland. Grosvenor Hotel, Chester. 7.30 p.m.

Gloucester.—Developments in Aviation in European Countries. P. B. Locke. The Wheatstone Hall, Brunswick Road, Gloucester. 7.30 p.m.

Luton.—Junior Night. George Hotel. 7.30 p.m.

6th January

Yeovil.—Air-to-Air Photography. L. Russell-Adams. Park School, Park Road (off Princes Street), Yeovil. 7.30 p.m.

10th January

Halton.—Films. Original Copy of "Hells Angels." Branch Hut, R.A.F., Halton. 6.45 p.m.

11th January

Boscombe Down.—The Domain of the Helicopter. R. Hafner. Main Dining Hall, Airmen's Mess, A. and A.E.E., Boscombe Down. 5.30 p.m.

12th January

Southampton.—Annual General Meeting, followed by Film Show. Institute of Education, University of Southampton. 7 p.m.

Weybridge.—The Mechanical Test Department: Its Organisation and Function. J. H. Cork, W. Astley, G. F. M. Hawkins. Vickers-Armstrongs Ltd., Weybridge. 6 p.m.

13th January

Glasgow.—Film Evening. Royal Technical College. 7.30 p.m.

14th January

Birmingham.—Visit to Wolverhampton.

17th January

Halton.—Compound Engines. E. E. Chatterton. Branch Hut, R.A.F., Halton. 6.45 p.m.

19th January

Coventry.—Dr. A. M. Ballantyne will give an illustrated talk on his visits to the Overseas Divisions of the Society. Wine Lodge, Coventry. 7.30 p.m.

24th January

Henlow.—The Large Transport Helicopter—Its Design Problems. Dr. G. S. Hislop. Building No. 62, R.A.F. Technical College, Henlow. 7.30 p.m.

25th January

Belfast.—The Helicopter—has it a future? F. H. Robertson. Kensington Hotel, Belfast. 7.30 p.m.

26th January

Preston.—The Domain of the Helicopter. R. Hafner. Queen's Hotel, Lytham. 7.30 p.m.

Weybridge.—Fuels and Lubricants for Aviation. Dr. C. B. Davies. Vickers-Armstrongs Ltd., Weybridge. 6 p.m.

27th January

Yeovil.—History of Helicopter Patents. L. H. Hayward. Park School, Park Road (off Princes Street), Yeovil. 7.30 p.m.

31st January

Halton.—Junior Members Night. Branch Hut, R.A.F., Halton. 6.45 p.m.

2nd **February**

Brough.—Air Accidents. Air Cdre. Sir Vernon Brown, C.B., O.B.E. Lecture Hall, Yorkshire Electricity Board, Ferensway, Hull. 7.30 p.m.

Chester.—Global Winds and Weather. C. S. Durst, O.B.E. The Grosvenor Hotel, Chester. 7.30 p.m.

Luton.—Controls and Stability. J. Wimpenny. George Hotel. 7.30 p.m.

Southampton.—The Light-weight Jet Engine. Dr. S. G. Hooker, O.B.E. Institute of Education, University of Southampton. 7 p.m.

3rd February

Cheltenham.—Area Lecture: Coventry, Birmingham, Gloucester and Cheltenham Branches. Comparisons of some Aircraft Propulsion Systems. Professor A. D. Baxter. St. Mary's College, Cheltenham. 7.30 p.m. (Coach from Coventry leaves Baginton 5.20 p.m., going via Whitley and Parkside.)

Elections

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

Frank Alfred Bristow
Thomas William Brooke-Smith (*from Associate*)
Peter Denis Burnett (*from Graduate*)
Dennis Lees Butler
Austen Marcus Chittenden
John Edward Clough (*from Graduate*)
Michael Trevor Corben (*from Graduate*)
Burton George Cour-Palais (*from Graduate*)
Alexander William Culmer
Jack Sidney Dean (*from Graduate*)
Kenneth George Dunn (*from Associate*)
Dennis Sidney Eburne (*Ex Graduate*)
George Alexander Elliott (*from Associate*)
John Henry Fulford
Kenneth Charles Garner
Donald Edward Gibbs
Kenneth Herbert Griffin (*from Graduate*)
Bernard Oliver Heath (*from Student*)
Jack Hope
William Aylwyn Jones
Joseph Stanley Linton (*from Graduate*)
Charles Hugh Miller
Reginald John Monaghan
John Frederick Norbury
Royal Malcolm Norgrove
Hugh Richard Pyne Patterson
Peter Robinson (*from Graduate*)
William Dennis Seabrook (*from Associate*)
Godfrey Alan Sharman
Vincent Henry Sydney-Smith
Ronald Stanley Herbert Toms
Sydney Allandale Urry (*from Graduate*)
M. Vasudevan
Jack Victor Athelstane Welbourn (*from Graduate*)

Associates

James Robert Campbell (*from Graduate*)
Walter Frederick Charlton
George Ernest Clark
Albert William Hallam
David Arthur Kirby Haselum
Palliser Alfred Milbanke Hudson
Martin Madders
James Parker (*from Student*)
Frederick George Taylor
John Taylor
Alan Joseph Timmins
Laurence Rudolf Trier
Reginald Henry Young

Graduates

Kenneth Burgin
James Burnett
Roy Frederick Burrows
Sydney Robert Cann
Francis Creagh-Osborne
Geoffrey Bower Ducker
Ronald Foxton Ferguson
Keith Foster
Michael John Goldsmith (*from Student*)
John Douglas Jones (*from Student*)
Subramanyam Chenna Keshu (*from Student*)
Peter David Royton Luscombe
Robin Middleton
William Gerald Moorhead
Frederick Bowen Powell (*from Student*)
Carl Robin Raynham
James Braddock Russell
John Rye
Eric William Savage
Gordon Raymond Walsh
Peter Westmoreland
Ian Armstrong Wilkinson

Students

Alan Arthur Butler
Marcel Désiré Bylo
Richard Edward Chilcott
Trevor William Claxton
Michael John Futcher
James Ernest Hackett
David John Hards
Brian Alfred Holland
Allan Eric James
John Michael McDermott
John Edward Thorn

Companions

Henry Fitzwilliam Gregory Cowley
William James Dicker

Elliott Memorial Prize

The Elliott Memorial Prize has been awarded to Corporal Aircraft Apprentice M. J. Evans, the aircraft apprentice of the January 1952 Entry at R.A.F. Halton who obtained the highest marks in the General Studies examination. The award will be presented to him at the Graduation Prize Giving at Halton on 15th December 1954.

Annual Subscriptions

Members are reminded that their annual subscriptions become due on 1st January 1955. The rates are:—

	Home			Abroad		
	£	s.	d.	£	s.	d.
Fellows	5	5	0	4	4	0
Associate Fellows	4	4	0	3	3	0
*Associates	3	3	0	3	3	0
Graduates (aged under 26)	2	2	0	2	2	0
Graduates (aged 26 and over)	2	12	6	2	12	6
Students (aged under 21)	1	1	0	1	1	0
Students (aged 21 and over)	1	11	6	1	11	6
Companions	3	3	0	3	3	0
Founder Members	2	2	0	2	2	0

* Any Associate elected before 1st October 1947 may, if he wishes, elect not to receive the Journal, and in this case his subscription will be reduced by £1 1s. 0d. to £2 2s. 0d.

It will avoid delay and confusion if members, when sending remittances for subscriptions, will state their names clearly and give their addresses and grades of membership. Remittances should be made payable to the Royal Aeronautical Society.

Journal Binding

Self-Binder Cases

Self-Binder cases of the "Easibind" type are available from the offices of the Society. These binders are for members who do not have their Journals permanently bound, or who wish to keep their Journals together during the year for binding later.

These cases will hold 12 Journals which are kept in place by means of flexible steel wires. Journals can be inserted or withdrawn easily without damage, so preserving the contents for permanent binding later. The Journals will open flat at any page.

The binder is strongly made in durable dark blue leather cloth on stiff board covers and has gold lettering on the spine. The year is not blocked on the spine but there is a panel on which members who wish to use the binder as a permanent case can put the date.

The cost is 11s. 6d. each including postage and packing for either the size to fit 1952 and previous Journals, or for the size to fit the bigger Journal (January 1953 onward). Orders and remittances should be sent direct to the Secretary at the Offices of the Society and it is *important to state whether the old size or new size is required.*

Permanent Binding

The new prices for permanent binding of Journals are:

1954 Volume (including packing and postage)	18s. 6d.
1953 Volume (including packing and postage)	19s. 0d.
Previous Volumes (including packing and postage)	18s. 0d.

Journals, with a note of the name and address of the sender, should be sent direct to The Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the Offices of the Society.

Changes of Address

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).	New address (in block letters)
Grade of Membership.	Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the Journal for the following month.

The Journal of the Royal Aeronautical Society
WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS
VOLUME 58 DECEMBER 1954 NUMBER 528

Propellers for High-Speed Aircraft

by

G. C. I. GARDINER, A.F.R.Ae.S. and P. BRETT, A.F.R.Ae.S.
(Chief Engineer and Chief Aerodynamicist, de Havilland Propellers Ltd.)

Introduction

In presenting this paper an attempt has been made to examine the development of current propeller theory and practice to cover the range of aircraft speeds between 450 and 550 m.p.h., which at 36,000 ft. represents a flight Mach number range of about 0·68 to 0·83. Inevitably in such a discussion it has been necessary to peep over the wall into the realms of higher speeds, but no serious attempt has been made to cover such a controversial region because of the lack of experimental data.

At the present time the propeller-turbine engine has established itself as the optimum power plant for aircraft of medium speed, up to 400 m.p.h., for medium or long range, while the jet engine has been used for aircraft designed to cruise at speeds greater than this. In the past few years, however, much evidence has been accumulated to show that a speed of 400 m.p.h. is by no means the limit for propeller applications, and that the advantages of the propeller can be maintained by suitable design up to a very much higher flight Mach number. It is interesting to recall that the Hornet is still very nearly the fastest propeller-driven aeroplane now flying; designed in the early 1940's, it was powered by piston engines and had propellers of conventional subsonic design. This aircraft in prototype form achieved a level speed of 485 m.p.h. at 25,000 ft., which corresponds to a propeller efficiency of something like 72 per cent. at a Mach number of 0·72; this value of efficiency was the best attainable at that time but would not bear comparison with the values required for present day commercial operation. It is for this reason that in the intervening years propellers have been fitted only to aircraft flying at considerably lower speeds, and it is only now that sufficient knowledge is available to design for speeds around 500 m.p.h. and to maintain the order of efficiency necessary to make the economical operation of large transport aircraft practicable.

Turbo-Prop or Turbo-Jet

Before considering the subject in detail it is as well to review the field of application of the propeller as a means of propulsion. Fig. 1 shows the comparative efficiencies of the propeller-turbine and turbo-jet systems on a fuel energy basis, the efficiency being defined as the ratio of the energy available for propulsion to the net energy produced by the gas generator system. This figure refers to flight above 36,000 ft. and is drawn for single rotation propellers, the optimum design of propeller and division of power within the propeller-turbine engine being assumed at each flight speed. At the lower flight speeds there is a marked advantage in efficiency in favour of the propeller-turbine, but as flight speed increases this advantage becomes progressively less until at 650-700 m.p.h. the efficiencies are comparable. Note that at the upper end of the speed range shown, the efficiency of the propeller-turbine system tends to be asymptotic to that of the turbo-jet: this is because, as flight speed increases, a progressively smaller proportion of the total power of the propeller-turbine engine must be put into the propeller if optimum propulsive efficiency of the system is to be maintained, until in the limit the propeller becomes redundant and the engine becomes a pure turbo-jet.

Efficient propulsion is not, of course, the only consideration affecting the designer; the propeller-turbine is a heavier power plant and brings with it a number of installation difficulties peculiar to itself. For this reason the speed at which the propeller-turbine is preferable to the pure jet from the overall point of view is lower than that suggested by pure efficiency considerations, and, in fact, a limit of about 550 m.p.h. is usually considered in this connection, at least for civil aircraft. There can be no question that the turbo-jet engine is the correct choice for very high-speed first class travel and also for front line military aircraft, where simplicity, lightness, and ease of installation and maintenance are

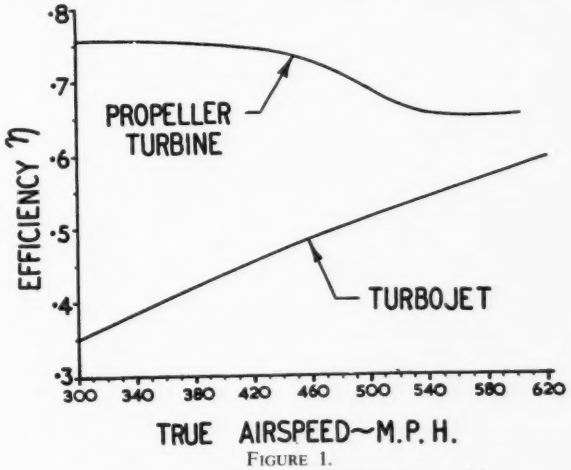

FIGURE 1.

Efficiency $\eta = \dfrac{\text{Energy available for propulsion}}{\text{Net energy produced by gas generator}}$

*Based on a Section Lecture given to the Society on 4th May 1954.

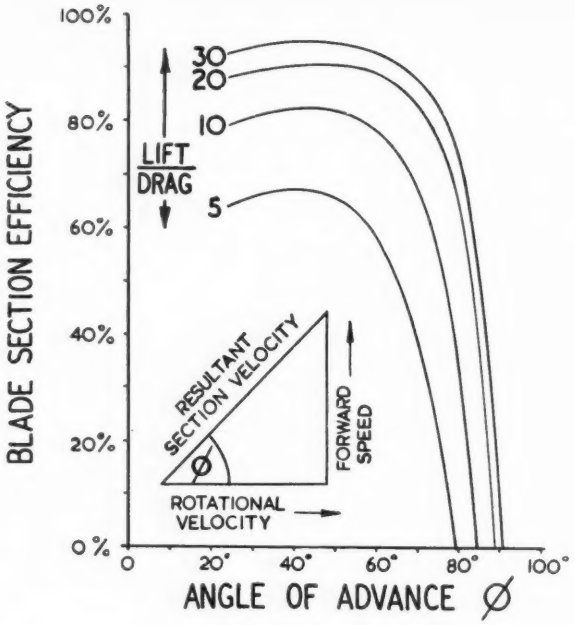

FIGURE 2.

of first importance; the propeller comes into its own for civil aircraft up to speeds of 500/550 m.p.h. and for military aircraft where long range and flexibility at medium or high subsonic speeds are important.

Mach Number Effects

It is customary to classify propeller types in one or other of three categories: subsonic, transonic and supersonic. These terms refer to the conditions under which the majority of the propeller blade is operating, and not to the speed at which the propeller itself is moving through the air. It is, for example, quite possible to envisage a supersonic propeller installed on a subsonic aircraft.

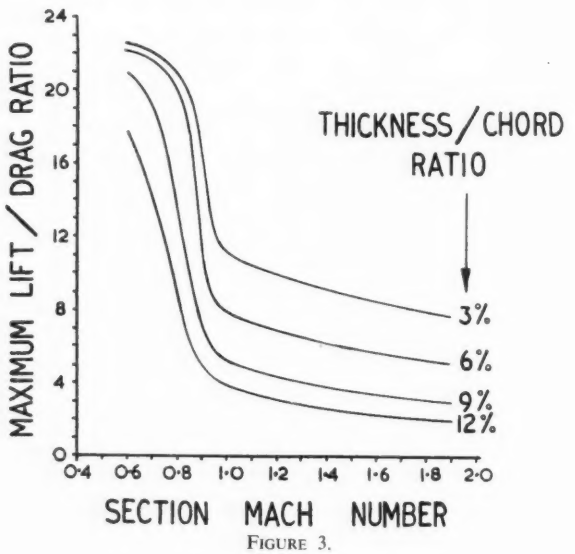

FIGURE 3.

Generally speaking, the trend from subsonic propellers through transonic to supersonic follows the upward trend in aircraft Mach number, and to explain the reasons for this it is necessary to consider the effect of increasing flight Mach number on certain fundamental characteristics of the propeller.

Figure 2 shows the variation of blade section efficiency with angle of advance for various values of section L/D. As the angle of advance ϕ increases with increasing forward speed, a point is reached where section efficiency begins to fall very rapidly with further increase in ϕ. When propeller helical tip Mach number is limited by consideration of noise to a value not much greater than 1·0, as in the case of a transonic propeller, this condition is reached in the most important region of the blade at flight speeds somewhere between 520 and 550 m.p.h. above 36,000 ft. If flight speed increases beyond this, the only means of restoring section efficiency and so maintaining a reasonable overall propeller efficiency, is to reduce the angle of advance by increasing the r.p.m. of the propeller. As this is done, the helical speed of the outboard sections of the blade becomes supersonic: this is the origin of the term supersonic propeller.

Figure 3 shows that although it is possible in this way to restore section efficiency to some extent, a sacrifice must inevitably be made in the value of lift/drag ratio as section Mach number increases. The curves show that the maximum lift/drag ratio of a blade section decreases very sharply over the transonic range and thereafter more gradually. In general, therefore, it is possible to restore section efficiency to some extent by increasing propeller r.p.m., although this will result in a reduction of L/D due to increased section Mach number. The curves illustrate the importance of the lowest possible thickness/chord ratio to maintain as high a value of L/D as possible.

The effect of the gradual reduction of propeller efficiency as flight Mach number increases is well illustrated by Fig. 4, which shows in general terms the approximate trend of efficiency of single rotation propellers with increasing flight speed. Here a regime of flight Mach number is allotted to each of the three types of propeller considered: subsonic, with blades about 6 per cent. thick at 0·7 radius; transonic, operating at tip Mach numbers of about 1·0 and with a thickness ratio at 0·7 radius of between 6 per cent. and 4 per cent.; and supersonic, with a value of between 4 per cent. and 2 per cent. Any point on this curve represents about the maximum efficiency obtainable with a practical propeller of the appropriate thickness/chord ratio designed for that particular flight Mach number.

The gradual reduction in efficiency of the subsonic propeller is due to the drop in section efficiency as angle of advance increases with flight speed above the optimum value of about 45°. The rapid decrease in the regime of the transonic propeller is due partly to increase in ϕ to about 60° at 0·7 radius, but mostly to the sharp fall of L/D as the helical speed of the outer and most important sections of the blade approaches a Mach number of 1·0. It is worth noting here that the efficiencies could be considerably improved by reducing

thickness/chord ratio below the values shown; this, however, would present a major structural problem at the large diameters associated with transonic propellers. In the region of the supersonic propeller, the reduction in propeller efficiency with increase in flight speed is more gradual since the angle of advance has been restored to near-optimum, and because above a Mach number of unity the L/D drops more slowly as section velocity increases.

Take-off Performance

Up to now we have dealt exclusively with performance in cruising flight, and would now like to discuss briefly the performance of the various types of turbine-propeller in take-off and climb. The general level of performance attained in these conditions with subsonic propellers is well known; in the larger sizes a take-off thrust at, say, 100 m.p.h. of about 2·5 lb./s.h.p. is usually attainable, while efficiency in a fairly fast climb approaches that in cruise. The take-off figure reduces to just over 2 lb./s.h.p. for the large transonic propeller, and to between 1·0 and 1·5 lb./s.h.p. for the smaller diameter supersonic propeller; performance of both these types in climb is often better than that in cruise owing to lower compressibility losses at climbing speeds. It is worth noting here that the performance of a propeller-turbine power plant using any of these types of propeller is invariably better at take-off, and usually better in climb, than that of a turbo-jet engine giving the same thrust in cruise.

Design Considerations

It now seems clear that, in Great Britain at any rate, development over the next few years will be directed mainly towards the transonic propeller, and in the remainder of this discussion we shall be dealing mainly with this type, treating the supersonic propeller merely as a logical development resulting from the requirement for even higher flight speed.

We turn now to the considerations affecting the configuration and aerodynamic design of propellers for high-speed aircraft. The design of the propeller is determined fundamentally by the levels of performance required in the various operating conditions; whereas in the past propellers have often been designed for take-off or climb conditions in the certainty that they will be reasonably efficient in a low Mach number cruise condition, propellers for high-speed applications must inevitably be designed for the actual cruise condition contemplated, since propeller efficiency is very sensitive to small design changes when the blade sections are operating at high Mach number. The design is also influenced by many other considerations connected with the design of both airframe and engine and much compromise is usually necessary.

The fundamental characteristic of the propeller is its diameter, and this is normally determined by the design of the airframe and the various installation problems associated with it. The most usual configuration is that of the conventional tractor propeller installed on an engine buried in the wing or in the fuselage nose; in this case diameter is generally determined by such

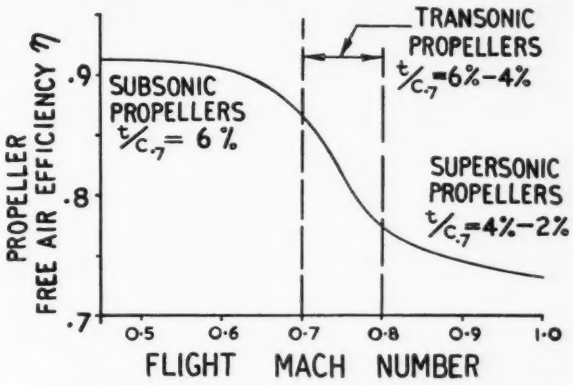

FIGURE 4. This curve indicates the maximum efficiency attainable with single rotation propellers of the type indicated designed for each particular flight Mach number. The size of propeller will therefore vary at each point on the curve.

considerations as fuselage and ground clearance, leading edge sweepback, and so on. Fig. 5 shows some typical layouts and it will be obvious that the tractor propeller is unattractive for multi-engined aircraft having a high degree of sweepback. Pusher propeller installations have been suggested to overcome this difficulty and are attractive in that by their use the drag increases experienced in the slipstream of a tractor propeller are largely avoided. This is an important consideration, since fairly severe increases in drag may result from a small increase in Mach number caused by the propeller slipstream when the wing as a whole is designed to operate near the point of drag rise. The pusher type of installation has the further advantage that the engine air intake is totally unobstructed and high intake efficiencies are therefore attainable.

Experience with pusher installations, however, has shown that the advantages are, in general, more than offset by the reduced efficiency of the blades operating

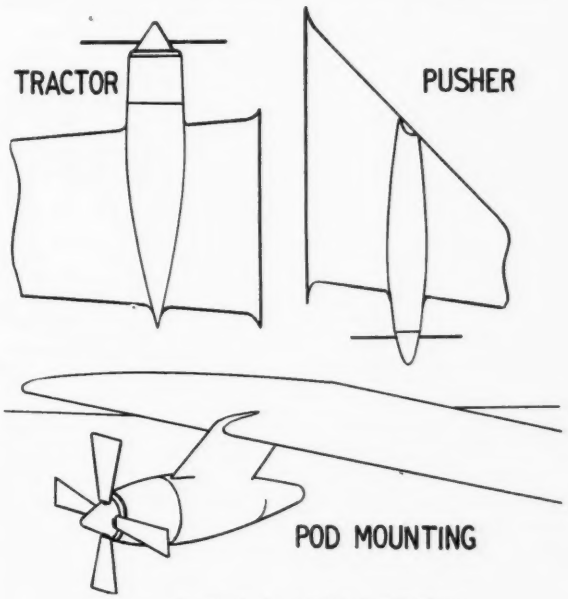

FIGURE 5. Typical propeller installations.

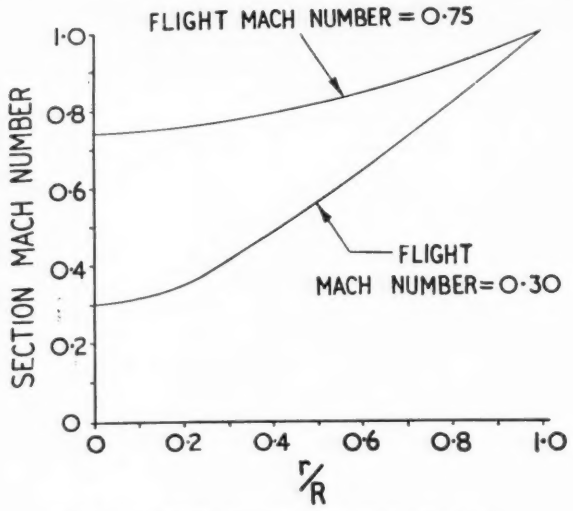

FIGURE 6. Mach number variation along the blade.

in the turbulent wing wake, and by the excessive increase in propeller weight necessary to cater for the very severe vibratory conditions under which the propeller must work in this configuration. An additional problem is the efficient disposal of the jet efflux, which makes an increasing contribution to the propulsive energy of the power unit as flight speed increases. These objections to the pusher installation become, if anything, more powerful as flight speed is increased and it appears that in cases where the tractor configuration must be abandoned because of high sweepback, the most satisfactory solution is to sling the engines in pods and to install tractor propellers which are either completely clear of the wing, or at least have their centres well below the wing surface. A pod installation of this type would minimise the slipstream drag difficulty and would permit a comparatively clean intake and jet exit design. With a pod-mounted configuration, propeller diameter is likely to be fairly restricted and this type of installation is therefore most suited to the supersonic propeller, in which adequate power absorption can be achieved at much smaller diameters, due to high rotational speeds.

With the propeller diameter established, the design problem broadly resolves itself into determining the optimum combination of total solidity and r.p.m. to absorb the engine power with the required efficiency.

Propeller Noise

The choice of r.p.m. introduces the important question of propeller noise. The curves of Fig. 6 show one interesting aspect of this question which becomes apparent as the flight speed increases into the high subsonic Mach number range. The figure shows the distribution of section Mach number along the blades of two propellers, one of which is operating at a flight Mach number of 0·3, and the other at a flight Mach number of 0·75; in both cases the helical tip Mach number is the same at a value of 1·0. It will be apparent from the shape of these curves that the high section Mach number over the entire blade of the high-speed propeller is due to the greater flight Mach number: at take-off, therefore, the section Mach numbers would be comparatively low and would result in a low noise level. The other propeller, which corresponds approximately to the familiar Harvard installation, derives its high section Mach numbers over the outboard part of the blade from the use of high r.p.m., and this propeller is therefore noisy during take-off and climb.

Much work has been done on the propeller noise problem in the past, but it has all related to tip speeds and flight speeds corresponding to current civil practice. Because of the lack of suitable propeller-driven aircraft capable of sustained flight at, or above, 500 m.p.h., it is still difficult to predict with certainty what noise level will result when the blade sections are operating transonically and the helical tip Mach number approaches 1·0 or exceeds it. Calculations suggest that there is no sudden increase in noise level as tip Mach number exceeds unity, but it is considered that the noise level corresponding to a helical tip Mach number of 1·0 or just over is about the maximum for which adequate sound proofing can be provided for the passenger cabin.

Recently consideration has been given to the possibility of phase synchronising the propellers of multi-engined aeroplanes, in other words maintaining individual blades of propellers on opposite sides of the fuselage in a definite angular relationship one to the other. Calculations suggest that although a considerable reduction in sound pressure may be achieved at specific points in the pressure field by a suitable choice of phase relationship, the effect is local and may be destroyed or even reversed at small distances from these points. It is unlikely, therefore, that the average noise level inside a fuselage would be appreciably reduced, but it is thought that the constant, and therefore less irritating, noise level resulting from phase synchronisation should be considerably lower than the peak levels reached in the "beats" occurring with propellers unsynchronised in phase. This possibility is at present being investigated in detail but

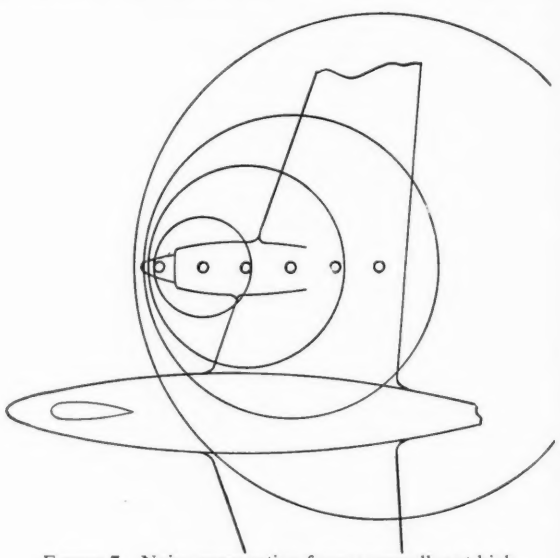

FIGURE 7. Noise propagation from a propeller at high subsonic flight speed.

it is as yet too early to draw any definite conclusions from the theory. Apart from this, it appears that within the limits of our present knowledge there is little that can be done in the design of the propeller itself to minimise the noise problem, and that once an adequate tip/fuselage clearance has been provided, the only means of adjusting the amount of noise created by the propeller is change of r.p.m., or flight speed such that the helical tip Mach number does not exceed a given arbitrary value, based upon previous experience.

With these points in mind, therefore, every effort is made in the design of the transonic propeller to limit the helical tip Mach number to a value not much greater than 1·0, and the r.p.m. and solidity are determined by this consideration. It is worth noting here that the design philosophy of the supersonic propeller is fundamentally different in this respect; in this case tip speed is already so high that noise level can no longer be considered as a factor in the design, and the designer enjoys freedom to select whatever combination of r.p.m. and solidity gives optimum efficiency. It seems fairly certain that the supersonic propeller would be unsatisfactory for civil applications merely from noise level considerations, since the weight of soundproofing material necessary to maintain a reasonable noise level within the aircraft would be quite unacceptable.

This argument does not necessarily apply to the military field, however, since the flight crew could be positioned well ahead of the propeller discs where, because of the high flight Mach number, the noise level would be much attenuated. This will perhaps be more readily understood by reference to Fig. 7, which shows in diagrammatic form the atmospheric propagation of noise from a propeller considered as a point source travelling at a Mach number of 0·9. At this flight Mach number, a sound wave does not reach an observer positioned ahead of the propeller until it has travelled a considerable distance from its point of origin in space, by which time its intensity will be much reduced.

Propeller Solidity

To return now to the transonic type of propeller, we have seen that the cruising r.p.m. is determined by noise level considerations in such a way that the helical tip Mach number is limited to a value of about 1·0, and the solidity of the propeller must therefore be chosen to permit efficient absorption of the engine power at the corresponding r.p.m. and at the diameter already chosen.

The total solidity required can be obtained in two ways, either by increase in the width of individual blades or by increasing the number of blades; five blades is about the maximum number that can physically be accommodated in a single rotation hub, and to accommodate a larger number of blades than this it is necessary to resort to a counter-rotating propeller.

In general, the counter-rotating type of propeller gives a higher efficiency than its single rotation counterpart at any given flight speed; this is because the much larger total solidity available permits the use of a lower rotational speed to absorb a given power, and thereby delays the adverse effects of compressibility. This type of propeller also achieves a higher induced efficiency

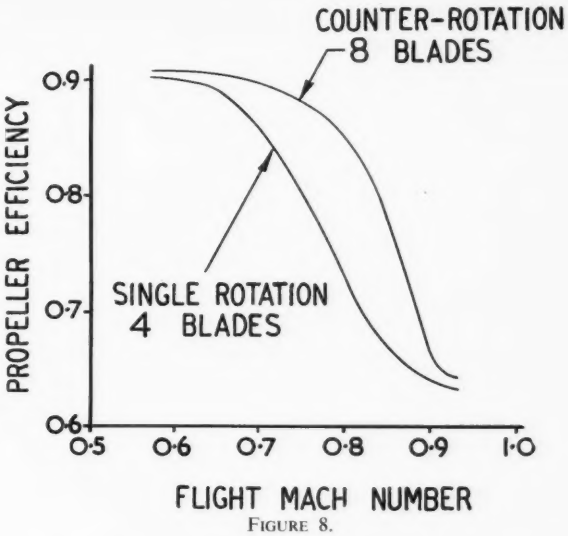

FIGURE 8.

owing to the fact that no rotation is imparted to the slipstream. Fig. 8 compares the typical performance levels over the range of flight Mach number from 0·6 to 0·9 attainable with single and counter-rotating propellers of the same diameter and identical blade design and for the same total power absorption. Optimum r.p.m. are assumed here for each flight speed and propeller type.

The penalty associated with the counter-rotating propeller lies in the much increased mechanical complexity and weight of this type; this is not confined to the propeller but applies also to the engine where additional shafting, reduction gearing, and so on, must be taken into account in assessing the relative merits of the two types of propeller.

It is worthy of note that the eight-bladed propeller here referred to would be about twice the weight of the corresponding four-bladed propeller, and Fig. 8 is therefore only intended to show comparative efficiencies.

A comparison of the merits of the single and counter-rotating types on an aircraft payload and range basis is possible for any given application, and in general it has been found that on this basis the advantage of the counter-rotating propeller is marginal, even for the longest ranges. In view of this and the extreme mechanical complexity of the counter-rotating hub, the current tendency in design is towards single rotation for all types of propeller, although Fig. 8 shows that over a comparatively small range of flight Mach number, probably above $M = 0{\cdot}8$, the counter-rotating propeller provides the only practical alternative to the true supersonic propeller; it might therefore find favour from noise considerations if an application of this kind were to be contemplated.

It has already been assumed that the maximum number of blades that can be accommodated in a single rotation hub is five. There are, however, certain difficulties associated with the use of five blades in one hub: these arise from the number of rotational speeds at which the fundamental edgewise and flatwise frequencies of the propeller blades are excited in a reactionless mode of vibration. It is considered quite unacceptable to

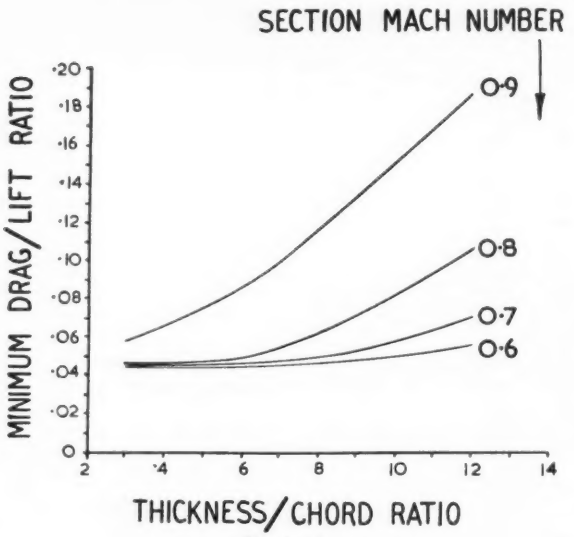

FIGURE 9.

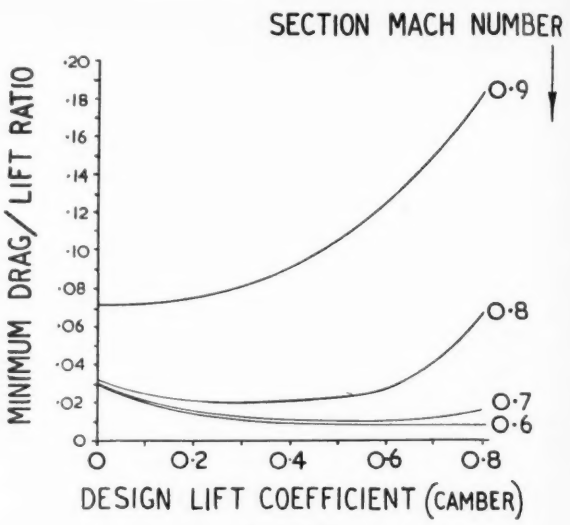

FIGURE 10.

permit a resonance at a fundamental edgewise frequency to lie in, or below, the normal running range of the propeller in view of the very high stresses which can be experienced in the region of such a resonance. To avoid running through an edgewise resonance, therefore, it is necessary to so design the propeller that edgewise resonances lie well above the normal operating r.p.m. range, and this presents great difficulty with the five-blade configuration as diameters increase, if excessive weight penalty is to be avoided.

In general, therefore, the four-blade single rotation configuration has been adopted as the best compromise for modern propeller designs. The necessary total solidity is obtained by varying both blade width and blade shape; the current tendency is towards greater blade width near the tip of the blade where it can perform more useful work. This results in either a square-tipped blade of parallel plan form or in one which increases in width towards a square tip; this latter plan form has the additional advantage of reducing blade centrifugal twisting moment and therefore the size of pitch change mechanism required to control the blade angle.

Blade Section Characteristics

The material and type of construction used for the blade is dependent upon a number of factors, the most important of which are blade diameter and width, maximum thickness permissible from performance considerations, blade stiffness requirements, and weight considerations. Before discussing these in greater detail it is relevant to consider the effect on propeller performance at high blade Mach number of the various aerodynamic design variables, the most important of which is thickness/chord ratio.

To obtain high propeller efficiency the aim must always be to obtain the lowest possible drag/lift ratio on the blade sections. Fig. 9 shows the variation of minimum D/L with thickness/chord ratio at various values of Mach number for a low camber N.A.C.A. 16 aerofoil.

It is clear that drag/lift ratio and therefore propeller efficiency becomes very sensitive to section thickness/chord ratio at the higher values of Mach number in the range considered; for example, with a propeller designed for a flight Mach number of 0·75 and having a tip Mach number of 1·0, an increase in t/c from 5 per cent. to 6 per cent. at 0·7 radius would produce a loss in propeller efficiency of some 4 per cent.

The other variable which must be carefully considered in the aerodynamic design of the blade is the blade section camber; Fig. 10 shows the effect on the section minimum drag/lift ratio of change of design lift coefficient, which defines the camber of an N.A.C.A. 16 section, for various section Mach numbers. In subsonic propeller applications where the section Mach number is comparatively low, the blade is usually designed with medium or even high camber to provide a reasonable level of take-off performance, but as section Mach number is progressively increased, it becomes essential to reduce the camber on the blade to maintain reasonable values of drag/lift ratio and, if necessary, to restore the take-off performance by increased solidity. Referring again to the propeller considered previously, an increase from 0·2 to 0·4 in the value of integrated design lift coefficient of the blades would result in a loss in propeller efficiency of just over 5 per cent.

In short, therefore, as section Mach number increases it becomes necessary progressively to reduce both thickness/chord ratio and camber of the blade sections, to maintain the level of propeller efficiency at an acceptable value.

Flutter

The requirement for low thickness/chord ratio is a vital factor in the structural design of the blade and does in fact set a limit to the size at which a blade can be made in solid Duralumin. The main reason for this is the necessity to provide sufficient torsional rigidity in the blade to avoid stalled flutter, an oscillatory condition which can arise when at least a part of the blade is operating at an incidence greater than that

corresponding to the stall, and which can lead to the development of very high torsional blade stresses. The avoidance of stalled flutter is invariably a critical design requirement for propellers designed for turbine engines, due to their high power at relative low r.p.m. and the resultant high values of blade incidence under static conditions.

This type of flutter can only be avoided by obtaining a sufficiently high value for the torsional frequency of the propeller blade to provide sufficient positive damping in the blade system. The so-called flutter boundary, across which the aerodynamic damping derivative changes from positive to negative, is represented in Fig. 11, which connects blade incidence with a non-dimensional frequency parameter for low Mach numbers. It will be clear from this curve that the design procedure for subsonic propellers is to increase the natural frequency of the blade until the point given by the co-ordinates of the incidence and the frequency parameter lies on the "no flutter" side of the boundary.

In general, increase in the torsional frequency of a blade of given construction can only be achieved by increase in blade thickness, and it follows that when the thickness of a dural blade required from flutter considerations exceeds that acceptable from the performance aspect, it becomes necessary to resort to a different form of blade construction having a higher torsional rigidity. This is one of the reasons for the adoption of the hollow steel type of blade construction, which is being specified for current transonic propeller designs as the only means of obtaining the necessary width of blade at the larger diameters with sufficient torsional stiffness and acceptable values of thickness/chord ratio and blade weight. This type of blade is already in use in a number of modern subsonic propeller installations.

Blade Root Sections and Spinners

Consider now the aerodynamic design of the blade root sections and spinner for high-speed propellers. It is essential to minimise the drag of the blade roots as far as possible if serious losses in overall efficiency are to be avoided. Careful design is also necessary to ensure that where the engine air intake is in the form of an annulus immediately behind the propeller, the blade

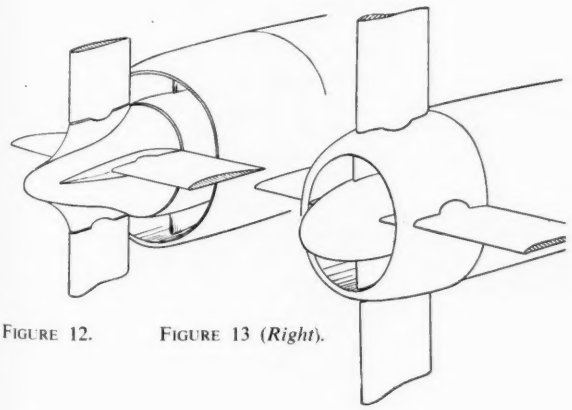

FIGURE 12. FIGURE 13 (*Right*).

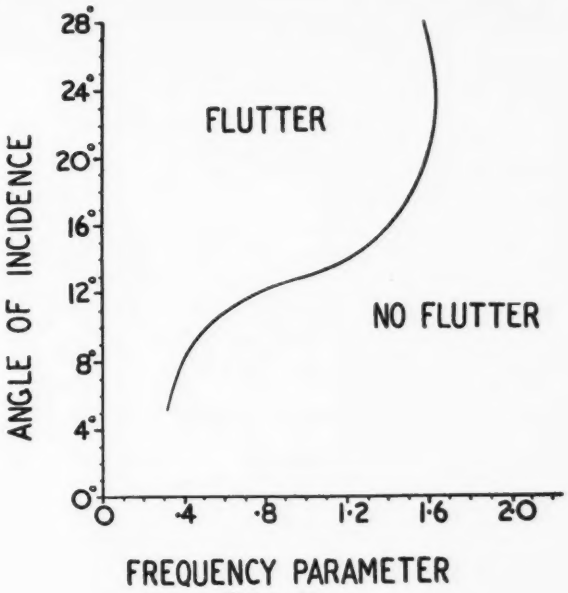

FIGURE 11.

roots do not create so much turbulence that intake efficiency is seriously affected. In general, the blade root thickness is determined solely by structural considerations, and to obtain reasonable values of thickness/chord ratio over these sections it may become necessary to increase the chord locally by the addition of some form of moulded cuff.

This is an important consideration since at a flight Mach number of 0·75, an increase in thickness ratio over the inboard part of the blade from 20 per cent. to 30 per cent. can result in a loss in propeller efficiency of nearly 3 per cent.

The design of the blade root/spinner juncture is critical in determining the flow into an annular air intake and hence the intake efficiency in critical flight conditions. The most attractive solution to this problem appears to be the so-called platform spinner, which is illustrated in Fig. 12. Here the spinner carries fixed fairings which are designed to coincide exactly with the inboard section of the blade in the design cruising condition; thickness/chord ratio of these fairings is not as critical as might be supposed at first sight, since, due to the presence of the engine air intake, the local Mach number is considerably lower than the free stream Mach number.

An alternative arrangement is that of the ducted spinner which is shown diagrammatically in Fig. 13. Here the spinner forms a forward extension to the engine air intake and circular blade roots pass through fixed internal fairings. While this configuration is excellent from the point of view of engine intake efficiency, it has a serious disadvantage in that the local Mach number at the outer spinner surface and over the inboard part of the blade can be higher than the free stream Mach number, and it becomes very difficult to achieve a sufficiently low thickness/chord ratio for the inboard blade sections to avoid serious performance losses. In addition, the ducted spinner presents a difficult structural

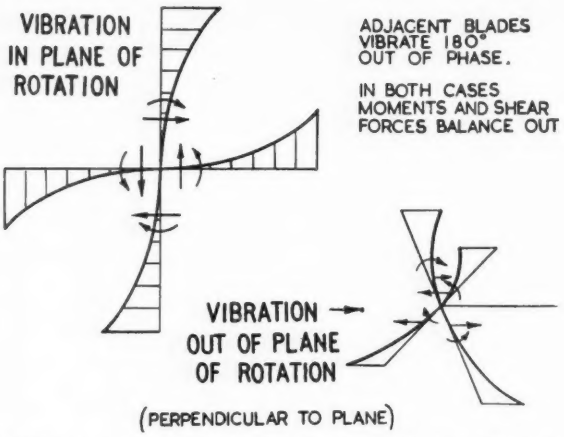

FIGURE 14. In-plane and out-of-plane reactionless modes of vibration.

and de-icing problem and is inevitably much heavier than the more conventional type.

A Design Example

To conclude this part of the paper, it may be of interest to outline the configuration which might be adopted for a propeller designed to absorb something like 3,000 s.h.p. in cruise at 500 m.p.h. above 36,000 ft., corresponding to a flight Mach number of about 0·75. This is inevitably a case for a transonic propeller, and, with an eye to civil operation, the helical tip Mach number would be limited to a value of about 1·0 from noise considerations; this corresponds to a rotational tip speed of between 600 and 650 ft. per second. The propeller would be of the single rotation type having four very wide blades of anything up to 2 ft. chord, depending on the diameter chosen, which must in any case be at least 15 ft. 6 in. to obtain reasonable efficiency. Blade camber would be limited to an integrated value of design lift coefficient of not greater than about 0·2, and thickness/chord ratio at 0·7 radius would be less than 5 per cent. The "free air" efficiency obtainable with such a propeller in the design cruise condition would be of the order of 80 per cent. It should be noted here that this efficiency could be considerably improved by the use of either much greater diameter and solidity, or by designing for a lower blade thickness/chord ratio; the former is likely to introduce weight and installation difficulties, while the latter would present a serious structural problem and could not be justified without considerably greater practical experience of the behaviour of thin blades than is available at present.

Structural Strength

From the structural aspect it may now be assumed that the number of blades and the diameter have been chosen from aerodynamic considerations, and the lightest propeller will obviously be that with the smallest acceptable shank size, *i.e.* with the highest permissible shank stresses. The initial survey, therefore, comprises calculation of mid-blade and shank stresses for the take-off condition, calculation of blade torsional frequency, centrifugal and air load twisting moments, hub stressing for centrifugal and thrust loads, and a check of the pitch change mechanism for operating loads. These are routine calculations and, for small diameter propellers, usually determine the propeller size.

However, with the advent of increasing power absorption requirements, we have to design for larger diameter propellers and higher solidities. In this case the basic investigations already outlined are not sufficient, and calculations must be made of aerodynamically excited 1*P* blade vibratory stresses and also the reactionless frequencies of the propeller, since in general single rotation propellers of four or more blades will be considered.

This latter problem does not exist on propellers with less than four blades.

When the air flow into a propeller is not normal to the plane of rotation, or when the velocity is not uniformly distributed across the disc, each propeller blade experiences a cyclic variation in air load as it rotates through one revolution. The resulting cyclic variation in bending moment produces a vibration of the blade with a frequency equal to the propeller r.p.m. This is termed an aerodynamically excited $1 \times$ propeller speed or 1*P* propeller blade vibration. These aerodynamically excited moments are augmented by inertia bending moments which increase as resonant conditions are approached.

The serious effect of 1*P* excited stresses was forcibly drawn to our attention several years ago by a hub failure on an aircraft installation in which the nacelles were inclined outwards by 4°, producing exceptionally severe aerodynamic excitation. This resulted in a hub fatigue failure after only 230 hours flying. Following a theoretical investigation and flight strain gauge tests, it was found necessary on this aircraft installation to change the blade design, involving a weight penalty of about 40 lb. per propeller, to crop the blades by 6 in. and finally to introduce a modified hub to obtain an unlimited propeller life. Subsequently, after discussion with the aircraft constructors, a nacelle angle modification was introduced into the next mark of aircraft; this resulted in such a marked improvement in aerodynamically excited vibratory stresses that it was found possible to revert to a lighter propeller at the original diameter.

It is now essential on all modern applications to make a theoretical investigation of 1*P* excited stresses for climb, cruise and other critical points on the flight envelope. For multi-engined aircraft the effects of fuselage interference are calculated and the propeller experiencing the worst aerodynamic excitation is subjected to a strain gauge investigation in flight, such tests being used to confirm the theoretical analysis of 1*P* stresses.

The actual calculation of the 1*P* moments is made by an iterative process similar to that used in blade stressing, allowance being made for edgewise and flatwise flexibility, rotation, and in-plane and out-of-plane vibration.

The computation is simplified by the use of matrix methods and although calculations of two conditions

(cruise and climb) would take about 200 man hours on desk machines, this can be reduced to about 30 man hours by the use of punched card equipment.

With single rotation propellers of four or more blades, it is necessary to investigate the reactionless modes of vibration of the propeller. As shown in Fig. 14, it is possible for the blades of a four-bladed propeller to vibrate in edgewise and flatwise reactionless modes of vibration in such a way that there is no reaction at the hub. This means that no moments are transmitted to the engine shaft and no damping of this mode of vibration can take place by interaction between the propeller and the engine shaft. As a result, continuous running at such a condition must be prohibited in order to avoid excessive vibratory stresses. With a four-bladed propeller, the reactionless condition occurs at a frequency twice propeller speed and is hence usually referred to as 2*P* flatwise and 2*P* edgewise vibration.

The variation of frequency with diameter for typical Dural propellers is shown on Fig. 15. With a five-bladed propeller, in addition to the two resonances for the four-bladed propeller there are also two further resonances occurring at three times propeller speed. In this case the 3*P* edgewise and 3*P* flatwise resonances will occur at approximately two-thirds of the propeller speed for the corresponding 2*P* resonances, the exact speed being modified by the reduced centrifugal effect at the lower propeller speeds. The 2*P* and 3*P* edgewise resonances can be raised appreciably by changing the shank size and, to a certain extent, by modification of the blade plan form. The 2*P* and 3*P* flatwise resonances can be modified by altering the thickness distribution. It will be seen that the five-bladed propeller introduces an additional design problem since it is considered essential to design any edgewise reactionless frequency out of, and above, the normal running range.

The method used for calculating 1*P* stresses can be extended with little modification for calculating edgewise and flatwise frequencies. These frequencies for a four-bladed propeller can be calculated in about 150 man hours with desk machines, or 20 man hours with punch card equipment.

To assess the permissible level of vibratory stresses it is essential to couple these investigations with a very comprehensive background of full scale fatigue testing of the hub and blade root retention, as well as the outboard blade sections. In the latter case the effect of service damage is also simulated.

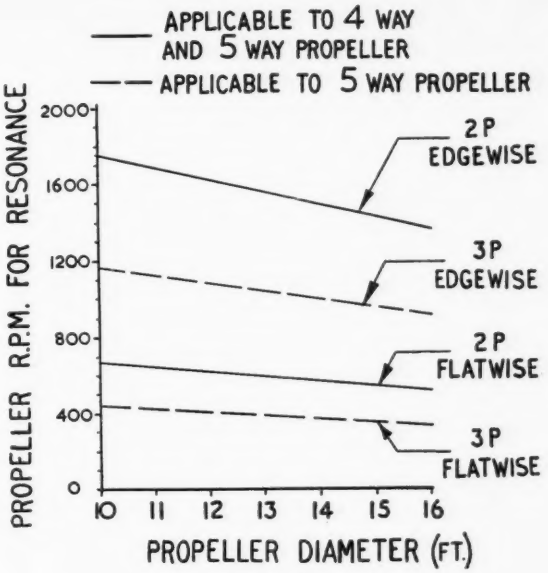

FIGURE 15.

Future Trends

From the earlier discussion on the main aerodynamic parameters it is clear that the main trend as aircraft forward speed increases is towards wider blades of ever-decreasing thickness/chord ratio.

As power loading increases and thickness ratio decreases, the torsional stiffness of the blade becomes increasingly significant and a satisfactory value can only be achieved by a hollow form of construction, unless severe performance and weight penalties are to be accepted.

Even on supersonic propellers, where very low values of thickness/chord ratio are essential, hollow blade construction presents the only practical solution unless a radical change of design philosophy is accepted. This would imply the design of the so-called "Super Critical Blade" in which the 1*P* critical speed and the flutter boundary are below the operating range. This latter condition would necessitate a control system which enabled the propeller speed to be increased to take-off r.p.m. at low blade angle and low power to avoid flutter. If this philosophy can be accepted, then the solid steel or solid titanium blade of extremely low thickness/chord ratio becomes a practical possibility.

Primary Instability of a Panel of Integral Construction with Unflanged Stiffeners

by

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Summary: A theory of primary failure of compression panels of integral construction with unflanged stiffeners is presented, involving rotation, or translation, or rotation and translation of the stiffeners with the corresponding distortion of the sheet without deformation of the cross sections in their own planes. The investigation shows that the failure may occur generally either by pure torsion of the stiffener with the associated lateral distortion of the sheet or by pure flexure in accordance with whichever mode yields a smaller stress. The theory is compared with the test results covering a fairly wide range of the dimensions involved. The theory is in complete agreement with the experiments. The accuracy of the result thus obtained indicates that the fillets at the junction of the skin and the stiffener are not important and their effects may safely be disregarded.

1. Introduction

In recent years considerable attention has been given to integral construction on account of the advantages claimed for this method of manufacture: namely (1) increase of structural efficiency, (2) reduced assembly time, (3) maintenance of smooth outer surface and (4) the part it could play in providing extremely thin wings for high speed aircraft.

The experiments conducted at Short Brothers and Harland Ltd.[5,6] have shown that the unflanged integral construction behaves extremely well in compression and a stress of the order of 60,000 lb./in.^{2} for aluminium alloys was developed in their tests on compression panels, without encountering any serious trouble. However in tests subsequently done at the Engineering Development Laboratory of the Bristol Aeroplane Co. Ltd.[9] a stress of about 69,000 lb./in.^{2} was obtained for a short panel 10 in. long, manufactured from a rolled plate of aluminium alloy to the specification DTD 683, and further it was noticed that the skin remained almost smooth until a stress of about 66,000 lb./in.^{2}; failure occurred as the rotation of the stiffeners rapidly increased as the failing stress (69,000 lb./in.^{2}) was reached.

It was inferred from the test results of Short Brothers and Harland Ltd.,[5, 6] on account of the inherent stiffness due to the skin, stiffener and fillet radius at the junction, that fixed ended conditions could be conservatively and tentatively employed for skin buckling and the stiffener local instability stresses. On the basis of these conclusions, the wing box structure designed and tested[6], has demonstrated that the advantages of the integral construction are worth very serious consideration.

Received 30th June 1954.

As far as is known, not much analytical work on compression panels of integral construction has been published, to provide an insight into the mechanism of the various instabilities involved and also to enable the designer to evaluate its advantages more precisely. However the Royal Aeronautical Society is now preparing Data Sheets[9] (the draft copies were kindly made available) for the estimation of the initial buckling stress of stiffened panels under compression. The method proposed comprises a class of deformations in which the cross sections are distorted in their own planes without rotation and translation. When this method is applied to the unflanged stiffener integrally machined skin panels, initial buckling of skin or stiffener could be obtained in certain cases. From the limited experimental data now available, it may be inferred (so far as the unflanged stiffener panels are concerned) that the cross-sectional distortions as suggested are encountered in cases in which the thickness of the stiffeners is much smaller than the skin thickness and their depth relatively large. The initial buckling in such cases need not necessarily be critical to constitute a total failure of the structure. The experiments have shown that sometimes the failing stress is about twice as much as this initial buckling stress.

In this paper an analysis is presented dealing with the primary instability of the structure involving the rotation, or translation, or rotation and translation of the stiffeners with the corresponding lateral distortion of the sheet. The stress predicted by the present analysis is critical and thus the maximum stress attainable for any given structure of integral construction.

The effect of the fillet radius at the junction of the stiffener and the skin has not been taken into account.

As indicated earlier where cross-sectional deformations in their own planes are likely to occur, the theory given here does not apply.

Notation

- A cross-sectional area of the stiffener
- a cross-sectional area of the sheet between consecutive stiffeners (bt)
- b stiffener spacing (measured from the median lines of the stiffeners)
- E Young's modulus
- G shear modulus $[=E/2(1+\upsilon)]$
- h depth of the stiffener measured from the median line of the sheet
- I_p polar moment of inertia of the stiffener with the sheet, with respect to the centre of rotation (area of the sheet bt is assumed to be concentrated at the junction of the sheet and the stiffener)
- J torsional constant of the stiffener
- J_{sh} equivalent torsional constant of the sheet
- L effective length of the panel (in the tests of the panels, where ends are clamped it is equal to one-half of the length of the panel)
- r perpendicular distance between the centre of rotation and the tangent line at any point on the median line
- s distance between the skin-stiffener junction and the centre of rotation
- t thickness of the sheet
- t_s thickness of the stiffener
- u circumferential co-ordinate along the median line
- w_s unit warping displacement with respect to the centre of rotation
- ω lateral displacement of the sheet
- Γ torsion bending constant
- υ Poisson's ratio
- θ angle of twist
- σ_{cr} critical stress

2. Analysis

The type of integral construction under consideration is shown in Fig. 1. It consists of a number of unflanged stiffeners of thickness t_s and depth h integrally machined with the sheet of thickness t from a single solid plate; the stiffeners are placed at a distance b apart as shown.

The type of failure investigated in this paper consists of translation or rotation, or rotation and translation of the stiffener with the associated lateral distortion of the sheet. The stress obtained by means of this theory constitutes the failing stress and therefore the type of failure is designated as primary failure.

In keeping with this definition any instability in which the cross sections are distorted in their own planes without translation and rotation may be called "secondary" or "local" instability.

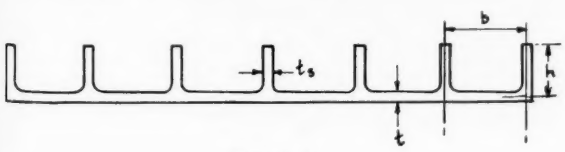

FIGURE 1.

2.1. PRIMARY FAILURE; TORSIONAL INSTABILITY

The critical compressive stress for torsional instability stress for torsional instability of an open section attached to a sheet is given by[1, 2]

$$\sigma_{cr}=\frac{G(J+J_{sh})+\Gamma\pi^2E/L^2}{I_p} \quad . \quad . \quad (1)$$

2.2. EVALUATION OF THE CONSTANTS Γ, J, J_{sh} AND I_p

2.2.1. Γ, *torsion bending constant*

Because of the symmetry of the stiffeners, they are assumed to rotate alternately, as shown in Fig. 2. As the stiffness of the skin in its plane is very large, the centre of rotation is assumed to lie in this plane at a distance s from the junction of the stiffener and skin.

The torsion bending constant is given by

$$\Gamma=\int_A w_s^2dA-\frac{1}{(A+a)}\left[\int_A w_sdA\right]^2 \quad . \quad (2)$$

where w_s is the unit warping with respect to the centre of rotation and is defined as

$$w_s=\int_0^u rdu \quad . \quad . \quad . \quad (3)$$

the distribution of which along the stiffener is shown in Fig. 3.

Substituting equation (3) in equation (2) and simplifying,

$$\Gamma=s^2h^3t_s\left\{\frac{1}{3}-\frac{1}{4}\frac{t_sh}{(bt+ht_s)}\right\} \quad . \quad . \quad (4)$$

This equation can be written as

$$\Gamma=\Gamma_0S^2 \quad . \quad . \quad . \quad (5)$$

where

$$\Gamma=h^3t_s\left\{\frac{1}{3}-\frac{1}{4}\frac{t_sh}{(bt+ht_s)}\right\}$$

2.2.2. *Torsional constant J of the stiffener*

It is given by

$$J=\tfrac{1}{3}ht_s^3 \quad . \quad . \quad . \quad (6)$$

2.2.2. *The equivalent torsional constant of the sheet, J_{sh}*

While the stiffener is twisted through an angle θ, the sheet is laterally distorted by ω at any point (x, z). The equivalent torsional constant of the sheet can be obtained as follows by the requirement that the strain energy stored in the sheet when it is laterally distorted must be equal to the torsional energy stored in a rod of constant J_{sh} subjected to the same twist θ.

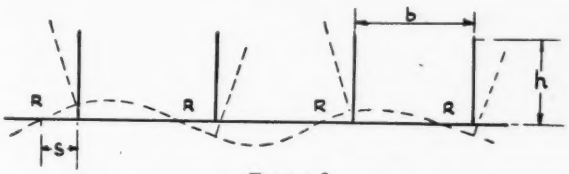

FIGURE 2.

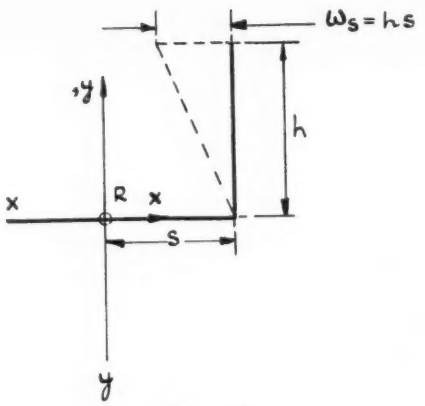

FIGURE 3.

The strain energy of the entire sheet between the two consecutive stiffeners of length L, is given by

$$V=\frac{D}{2}\int_{z=0}^{L}\int_{x=-b/2}^{b/2}\left\{\left(\frac{\partial^2\omega}{\partial x^2}+\frac{\partial^2\omega}{\partial z^2}\right)^2-2(1-\upsilon)\left[\frac{\partial^2\omega}{\partial x^2}\frac{\partial^2\omega}{\partial z^2}-\left(\frac{\partial^2\omega}{\partial x\partial z}\right)^2\right]\right\}dx\,dz \quad . \quad . \quad (7)$$

(Ref. 10, p. 307)

where

$$D=Et^3/12(1-\upsilon^2)$$

The lateral deflection of the sheet may be assumed to be given by (*see* ref. 2)

$$\omega=\theta_0\sqrt{S^2+\left(\frac{b}{\pi}\right)^2}\sin\frac{\pi z}{L}\sin\left(\frac{\pi x}{b}+\phi\right). \quad (8)$$

where

$$\phi=\tan^{-1}\left(\frac{s\pi}{b}\right)$$

Substituting equation (8) into equation (7) and integrating, we have

$$V=\theta_0^2\,D\frac{\pi^2 bL}{8}\left(s^2\pi^2+b^2\right)\left(\frac{1}{L^4}+\frac{2}{L^2b^2}+\frac{1}{b^4}\right). \quad (9)$$

The angle θ is given by

$$\theta=\theta_0\sin\frac{\pi z}{L} \quad . \quad . \quad . \quad (10)$$

The energy stored in a rod of torsion constant J_{sh} and length L subjected to this twisting is

$$V_e=\theta_0^2\frac{\pi^2}{4L}GJ_{sh}. \quad . \quad . \quad (11)$$

Equating V, equation (9) to V_e, equation (11) and solving for J_{sh}, we have

$$J_{sh}=bt^3\left\{0{\cdot}238+0{\cdot}119\left(\frac{L}{b}\right)^2+0{\cdot}119\left(\frac{b}{L}\right)^2+\left(\frac{s}{L}\right)^2\left[1{\cdot}175+2.35\left(\frac{L}{b}\right)^2+1{\cdot}175\left(\frac{L}{b}\right)^4\right]\right\} \quad (12)$$

This equation can be written as

$$J_{sh}=B_0+BS^2 \quad . \quad . \quad . \quad (13)$$

where

$$B_0=bt^3\left\{0{\cdot}238+0{\cdot}119\left(\frac{L}{b}\right)^2+0{\cdot}119\left(\frac{b}{L}\right)^2\right\}$$

and

$$B_s=\frac{bt^3}{L^2}\left\{1{\cdot}175+2{\cdot}35\left(\frac{L}{b}\right)^2+1{\cdot}175\left(\frac{L}{b}\right)^4\right\}$$

2.2.4. *Polar moment of inertia, I_p*

The polar moment of inertia of the stiffener and the sheet about the centre of rotation is given by

$$I_p=(ht_s+bt)s^2+\tfrac{1}{3}h^3t_s \quad . \quad . \quad (14)$$

the area of the sheet (bt) is assumed to be concentrated at the junction of the sheet and the stiffener.

Equation (14) can be written as

$$I_p=A_0s^2+I_s \quad . \quad . \quad . \quad (15)$$

where $A_0=(ht_s+bt)$

and $I_s=\tfrac{1}{3}h^3t_s$

Now substituting equations (4), (13) and (15) in equation (1) and rearranging the terms

$$\sigma_{cr}=\frac{s^2(BG+1{\cdot}0\pi^2E/L^2)+G(J+B_0)}{A_0s^2+I_s} \quad . \quad (16)$$

The stress is maximum or minimum if s is the root of the equation

$$\frac{d\sigma_{cr}}{ds}=0 \quad . \quad . \quad . \quad (17)$$

Differentiating equation (16) with respect to s, equating the resultant to zero and simplifying, we have

$$\frac{d\sigma_{cr}}{ds}=\frac{2s\{I_s(BG+1{\cdot}0E\pi^2/L^2)-A_0G(J+B_0)\}}{(A_0s^2+I_s)^2}=0 \quad (18)$$

Therefore $s=0$ is the root of equation (18). Putting $s=0$ in equation (16), the required stress is given by

$$\sigma_{cr}=\frac{G(J+B_0)}{I_s} \quad . \quad . \quad . \quad (19)$$

Substituting the value of B_0, J, J_{sh} and I_s and putting $G=0{\cdot}4E$, equation (19) can be written as

$$\frac{\sigma_{cr}}{E}=0{\cdot}4\left\{\left(\frac{t_s}{h}\right)^2+0{\cdot}357\left(\frac{b}{h}\right)\left(\frac{t}{t_s}\right)\left(\frac{t}{h}\right)^2\left[2+\left(\frac{L}{b}\right)^2+\left(\frac{b}{L}\right)^2\right]\right\} \quad (20)$$

In application of this equation the use of tangent modulus E_T in place of the Young's modulus E for stresses in the plastic region, is found to be satisfactory.

The other root of the equation (18) is $s=\infty$. This corresponds to the flexural mode in which the centre of rotation is situated in the plane of the sheet at infinity.

2.3. DISCUSSION OF THE RESULT

It is shown above that the centre of rotation must lie at the junction of the sheet and the stiffener. As a

TABLE I

MODES OF FAILURE

Panels	t_s	t	b	h	$2L$	t_s/t	b/h	L/b	*Mode of failure* Theory	Test
Short Bros. panels	IN.	IN.	IN.	IN.	IN.					
A	0·075	0·087	1·738	0·598	7·03	0·95	2·9	2·05	Flexure	Flexure
B	0·115	0·087	2·05	1·055	24·8	1·32	2·0	6·3	Flexure	Flexure
C	0·059	0·075	1·738	0·547	9·50	0·785	3·19	2·05	Flexure	Flexure
E	0·112	0·05	2·05	1·055	6·25	2·24	2·0	1·56	Torsion	Torsion
B.A.C. panels										
Long 1A	0·142	0·1	2·5	1·45	35·5	1·42	1·73	7·1	Flexure	Flexure
Short 1B	0·142	0·1	2·5	1·45	10·0	1·42	1·73	2·0	Torsion	Torsion

TABLE II

TORSIONAL MODES

VALUES OF σ_{cr}/E_T AT FAILURE

Panels	t_s	t	b	h	L	t_s/t	b/h	L/b	*Theory*	*Test*
Short Bros. panel	IN.	IN.	IN.	IN.	IN.				σ_{cr}/E_T	
E	0·112	0·05	2·05	1·055	3·13	2·24	2·0	1·56	0·00584	0·0059
B.A.C. panel										
1B	0·142	0·1	2·5	1·45	5	1·42	1·73	2·0	0·00908	0·0097

result of this the torsion bending constant Γ as given by the equation (4) is zero and hence there is no coupling between torsional and flexural instabilities. The failure that could occur is either by torsional instability of the stiffener with the associated buckling of the skin as predicted by the equation (20) or pure flexure according to whichever mode gives a smaller stress.

3. Comparison of the Theory with the Experiments

Firstly the modes of failure as predicted by means of the theory for the panels tested at Short Brothers and Harland Limited and the Engineering Development Laboratory of the Bristol Aeroplane Co. Ltd. are compared with the actually observed modes. They are given in Table I. Secondly the values of (σ_{cr}/E_T) for torsional instability as given by equation (20) for the panels which failed in torsion are given in Table II, together with the test result.

If the failing stress is in the plastic region the tangent modulus E_T in place of the Young's modulus E is used. For any given value of the ratio stress/tangent modulus the corresponding critical stress can be directly obtained from the curve in which the stress is plotted against this ratio.

It may be noted that the foregoing tests although limited, cover the ranges $t_s/t = 0{\cdot}785$-$2{\cdot}24$, $b/h = 1{\cdot}73$-$3{\cdot}19$, $L/b = 1{\cdot}56$-$7{\cdot}1$.

Photographs of the B.A.C.-1B panel after failure are given in Figs. 4 and 5. In Fig. 6, the torsional and

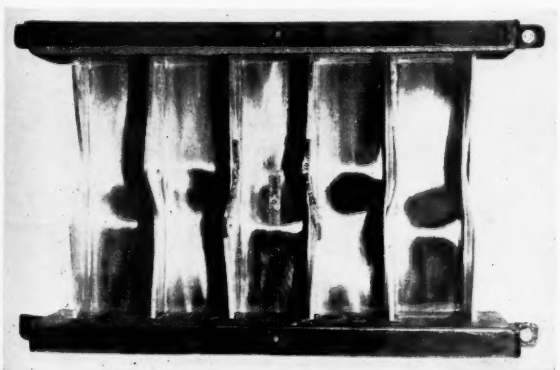

FIGURE 4. Torsional instability. B.A.C.-1B panel after failure.

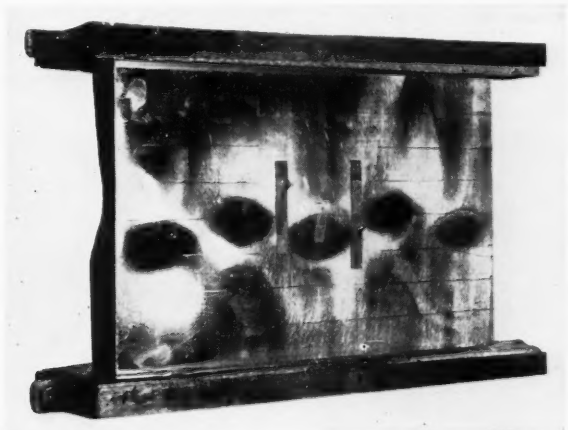

FIGURE 5. Torsional instability. B.A.C.-1B panel after failure.

flexural modes are represented non-dimensionally as well as independently of the material by plotting σ_{cr}/E_T against the slenderness ratio (l/K) of the panel for various values of A_s/bt (where $A_s=ht_s$) with the result of the experiments.

It may be seen that the theory is in complete agreement with the tests. Out of the seven panels tested[5, 9] six panels have failed in accordance with the theory, four of them failing in flexure and two in torsion. However one panel having the configuration[5] (Short Brothers panel c) $t_s/t=0{\cdot}65$, $b/h=2$ and $L/b=1{\cdot}56$, seems to have failed differently. The application of the method suggested in R.Ae.S. draft Data Sheet shows that the initial stability stress observed agrees very well in this case with the predicted buckling stress. However the panel did not fail at this stress but attained at failure nearly twice as much as this initial buckling stress.

4. Conclusions

The integral machined panels with unflanged stiffeners could fail in compression either due to the torsional instability of the stiffeners with the associated lateral distortion of the sheet, or in flexure in accordance with whichever mode yields a smaller stress, provided that the stiffeners are not much thinner than the sheet.

The good agreement between the theory and the test, without the fillets at the junction being considered, shows that the fillets are not important and their effects can safely be disregarded.

ACKNOWLEDGMENT

The author wishes to thank the Bristol Aeroplane Company Ltd. for permission to publish this paper. His thanks are also due to H. Giddings and J. F. M. Oram for interest in the work presented in this paper.

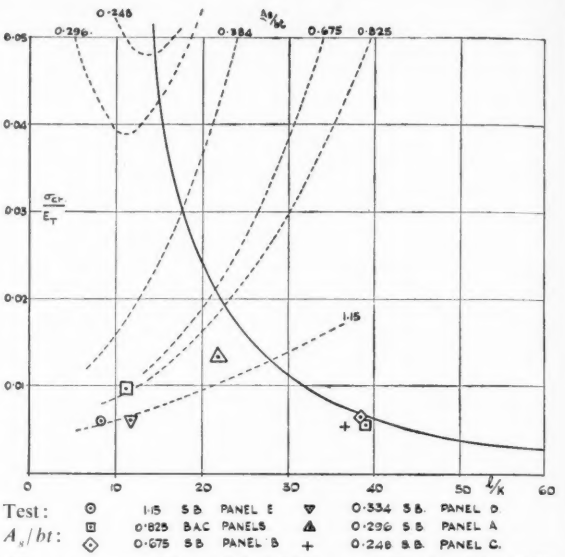

FIGURE 6. Integral machined panels.

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Effects of Fuel Type on the Performance of Aero Gas Turbine Combustion Chambers, and the Influence of Design Features

by

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SUMMARY: The performance of aero gas turbine combustion chambers is discussed under the following headings: Combustion efficiency, combustion stability, ease of ignition, deposits, exhaust temperature variation, and smooth combustion. It is shown that, as assessed by these criteria, combustion chamber performance can be significantly affected by fuel characteristics; also that the effects of fuel type can be greatly modified by equipment design changes. The conclusion is that most of the problems aggravated by fuel characteristics are better solved by modifications to equipment, if fuel availability and cost are not to be adversely affected.

Introduction

Since the advent of the aircraft gas turbine considerable research has been done at the Thornton Research Centre of the "Shell" Petroleum Company, on the general fuel problems connected with this new prime mover. This work has shown that, under certain (often extreme) operating conditions, some fuels can show advantages compared with others, and in fact quite a number of generalisations can be made. It has also been noticed, however, that performance differences between fuels observed under certain conditions are often greatly reduced, or even reversed, under other conditions or with changed combustion chamber configurations. In this paper is presented information derived from work at the Thornton Research Centre concerning the performance of fuels in gas-turbine powered aircraft and the effects of design features.

Experience with gas turbine combustion chambers has led to the adoption of six main criteria by which the performance of various fuels is judged. These are:

1. Combustion efficiency
2. Combustion stability
3. Ease of ignition
4. Deposit-forming tendency
5. Exhaust temperature variation
6. Smooth combustion.

Combustion intensity and pressure-loss are also combustion chamber characteristics which may be influenced indirectly by fuel properties, in any attempts to design a chamber satisfactorily to utilise a particular type of fuel.

In the present paper, chambers typical of the two basic types in contemporary use, the spray-injection and vapour-injection types, are considered. The two types are shown schematically in Figs. 1 and 2; for the purposes of the following discussion the chambers can be regarded as possessing two essential zones—the combustion zone where combustion proper occurs, and the dilution zone where the bulk of the air (usually about three-quarters of it) is fed in and dilutes and cools the gases from the combustion zone to temperatures acceptable to the turbine. In the spray-injection type, fuel is injected into the combustion zone in the form of a fine conical spray which vaporises readily in the hot gases; in the vapour-injection type, fuel is squirted into the inlet of the vaporising device (tubes in the example shown) and vaporises as it passes through the vaporiser together with some air into the combustion zone (from which the vaporising heat is extracted through the tube walls).

Received December 1953.

1. Combustion Efficiency

(*i*) *Spray-Injection-Type Combustion Chambers*

Exploratory work on a combustion chamber (A) from an early type of engine established that conditions could exist in a combustion chamber which allowed different fuels to give significantly different performances. This is illustrated in Fig. 3, where CO_2 combustion efficiency* is plotted against simulated engine speeds. Fig. 3 shows that although the test fuels (*see* Table 1) were substantially equal in performance at normal operational engine speeds (10,000 to 16,500 r.p.m.), significant differences appeared at lower speeds, increasing as speed was reduced, *i.e.* as air flow, air pressure, fuel flow and fuel-atomising pressure were reduced. The inference from these results was that, broadly, fuel performance at the lower speeds was

*CO_2 combustion efficiency is defined as the ratio:

$$\frac{CO_2 \text{ actually present in exhaust gases}}{CO_2 \text{ obtained theoretically from perfect combustion}} \times 100\ \%$$

The difference between CO_2 combustion efficiency (which is easily and accurately obtained by exhaust gas analysis) and true (heat balance) combustion efficiency is small, and may be ignored for the purposes of this paper.

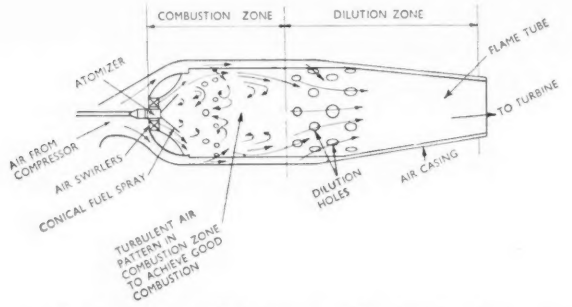


FIGURE 1. Typical spray-type combustion chamber.

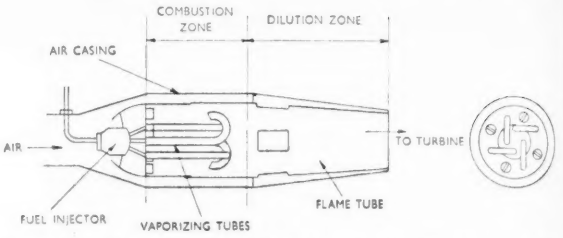


FIGURE 2. Typical vapour-injection type combustion chamber.

better with fuels of higher volatility and lower aromatic content. It was found also that despite fuel performance differences, the combustion loss at a given speed, accounted for by carbon monoxide in the exhaust, was substantially constant for each of four fuels (D, F, G and SR.312, the only fuels for which CO was determined) although that due to unburnt hydrocarbons varied considerably. Further investigations on the same chamber, at low air flow and with one fuel only, showed that whereas at the richer mixtures embracing normal engine operation the loss lay predominantly in CO, at weaker mixtures the loss lay mainly in unburnt hydrocarbons, largely as a result of very poor fuel atomisation. These results indicated that air flow conditions and degree of fuel atomisation (as affected by engine conditions or by the fuel physical properties) had large effects on relative fuel performance.

The results of further work in this chamber showed that at high air flow, implying vigorous air/fuel mixing, performance differences between fuels of widely different chemical and physical characteristics were insignificant. At low air flows, however, where air/fuel mixing was relatively poor, this was not so, as shown in Fig. 4. Thus toluene, an aromatic fuel, gave significantly lower efficiencies than did iso-octane, a paraffinic fuel of similar volatility. Fig. 4 also shows, however, the beneficial effect of using an atomiser of smaller flow-number (*i.e.* better fuel atomisation) in increasing the performance of both fuels and reducing the differences between them. No significant effects of T.E.L. (ignition inhibitor) or di-tertiary-butyl-peroxide (ignition promotor), added to the fuel, were observed.

It should be noted that where atomisation is relatively poor, increased fuel volatility can often have a beneficial effect on performance, as illustrated in Figs. 5 to 8; these results were obtained on combustion chamber B, which was one of the same basic design as chamber A, but was designed for greater throughputs, and had a greater diameter and a smaller length/diameter ratio. Fig. 5 shows that, at high-altitude idling conditions and with coarse atomisation (spill atomiser operated at low input flow), gasoline performed better than the less volatile kerosine and the still less volatile gas oil. Fig. 6 shows, however, that an improvement in

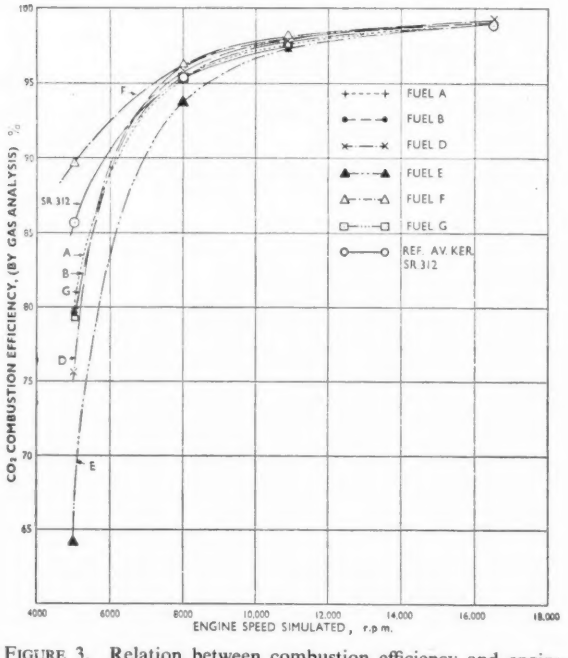


FIGURE 3. Relation between combustion efficiency and engine speed at sea-level static conditions (combustion chamber A.)

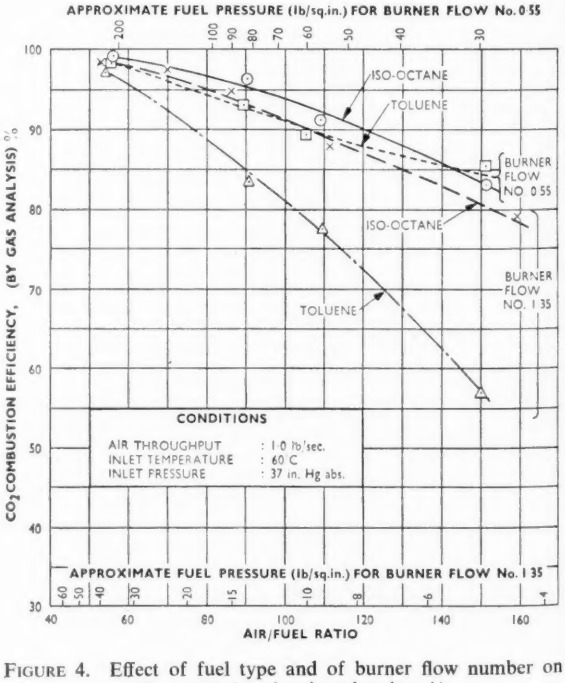

APPROXIMATE FUEL PRESSURE (lb/sq.in.) FOR BURNER FLOW No. 0·55
ISO-OCTANE
TOLUENE
BURNER FLOW NO. 0·55
ISO-OCTANE
BURNER FLOW NO. 1·35
TOLUENE
CONDITIONS
AIR THROUGHPUT : 1·0 lb/sec.
INLET TEMPERATURE : 60°C
INLET PRESSURE : 37 in. Hg abs.
APPROXIMATE FUEL PRESSURE (lb/sq.in.) FOR BURNER FLOW No. 1·35
CO2 COMBUSTION EFFICIENCY, (BY GAS ANALYSIS) %
AIR/FUEL RATIO

FIGURE 4. Effect of fuel type and of burner flow number on performance (combustion chamber A).

TABLE I

FUEL PROPERTIES

Fuel	A S.T.M. distillation (°C.)					C/H ratio	Sp. gr. at 60°F.	Viscosity cs at 100°F.	Aromatics %w.	Gum content mg./100 ml.	Remarks
	I.B.P.	10%	50%	90%	F.B.P						
Aviation Kerosine	159	174	213	254	276	6·01	0·805	1·52	8·6	—	Reference SR.312 (app. JP-1)
Fuel A	143	161	197	241	262	6·43	0·821	1·23	21·9	41	Vaporising oil
B	188	198	212	233	249	6·06	0·809	1·62	15·4	5	
C	186	200	220	259	279	6·35	0·828	1·77	20·5	—	Diesel fuels
D	151	202	227	262	288	6·75	0·862	2·41	28·8	97	Diesel fuels
E	188	206	222	264	309	6·85	0·871	2·24	23·0	—	Hydrogenated creosote
F	87	112	163	215	236	5·90	0·781	0·87	10·6	5	American JP-2 type
G	184	203	233	273	297	6·00	0·819	2·12	4·4	—	Hydrogenated gas oil
H	39	89	188	251	276	6·43	0·807	—	30	—	Experimental fuel of JP-3 type
J	53	125	185	224	245	6·2	0·779	—	22	—	Wide-cut fuel of JP-4 type
K	59	89	152	242	266	5·81	0·764	1·14	16·1	3	American JP-2 type
C_5-C_8 Olefins	34	51	73	95	106	6·77	0·695	0·40	—	—	Typical cracked waxes
C_5-C_{18} Olefins	52	93	206	290	315	6·62	0·771	1·10	—	—	Typical cracked waxes
Untreated gas oil	195	234	277	340	371	6·65	0·851	3·55	22·1	—	Sulphur content 0·64% *w*
Hydrofined gas oil	204	232	275	355	378	6·42	0·848	4·22	22·6	—	Sulphur content 0·15% *w*
Untreated cracked gas oil	195	235	265	319	*	7·35	0·896	3·93	—	—	* 98% at 371°C
Lye treated cracked naphtha	68	105	143	190	211	6·59	0·803	0·88	—	54	
Mixed octylenes	97	104	108	112	124	5·92	0·738	0·64	—	944	
50% Lye treated cracked naphtha 50% Fuel A	88	128	174	221	260	6·51	0·812	—	—	48	
18% Mixed octylenes 82% Fuel A	118	137	189	238	268	6·34	0·807	—	—	204	Contains equal concentrations of aromatics and unsaturates
Pool gas oil	199	240	290	369	—	6·75	0·859	4·5	20·2	—	
Light solvent (70-95°C)	72	75	80	90	94	—	—	—	5·0	—	A light hydrocarbon solvent
Gasoline	43	77	116	158	188	6·10	0·745	0·59	—	—	
Gas oil	184	207	251	315	346	6·50	0·820	2·27	20 app.	—	Light diesel fuel
Fuel X	38	75	141	258	283	6·4	0·779	0·82	30	—	JP-3 type
Fuel Y	94	110	152	259	288	6·2	0·809	0·90	—	—	As Fuel X less light fractions
Reference gas oil	204	216	228	245	287	7·1	0·855	2·1	—	—	A diesel research fuel
Benzene	—	—	80	—	—	12·0	0·882	—	100	—	Commercial benzol—95% pure benzene
Toluene	—	—	111	—	—	10·5	0·869	—	100	—	Commercial grade
Xylene	—	—	140	—	—	9·6	0·870	—	100	—	Commercial grade
Cumene	—	—	150	—	—	9·0	0·864	—	100	—	
Isododecane	161	171	180	188	202	5·5	0·767	—	—	—	Commercial grade
Iso-octane	96	—	98	—	109	5·3	0·695	—	—	—	Reference S_1

atomisation (changing from low to high input flow) at the same air flow conditions reversed the position, although efficiency with gasoline was not significantly changed. It should be noted that the generally low performance of the combustion chamber, at the idling conditions appropriate to Figs. 5 and 6, is due to a combination of low air pressure (which itself has adverse effects on combustion reactions, mixing rates, and so on, from the present viewpoint) and relatively low volume throughput (further reducing mixing rates); low performance due to these causes can be improved to important extents only by better chamber design.

Figures 7 and 8 (high altitude cruise conditions) confirm the tendency for better atomisation to improve performance more for the less volatile fuels. The generally better chamber performance here is due largely to the much higher operating pressures and air flows. It will be observed that the very wide-cut* fuel performed satisfactorily under these conditions. In this connection it should be noted that the performance of an atomiser can be adversely affected by the fuel viscosity, which might reach a prohibitive value if the fuel temperature became too low. Fig. 9 illustrates effects of viscosity on atomiser performance as affecting combustion efficiency. It is clear that fuel viscosity can have large adverse effects, but also that these effects can be greatly mitigated by improved atomiser design; the spill-type atomiser, for example, shows a marked superiority in this respect to all the others.

When considering the performance of a combustion chamber employing a spill-type atomiser, as in the present case, it should be remembered that for a particular input flow the spray-cone angle increases as output decreases; also, for a given output, spray-cone angle increases as input increases. Fuel properties will also affect the cone angle to some extent. It has been

*The 50/50 gas oil/gasoline blend.

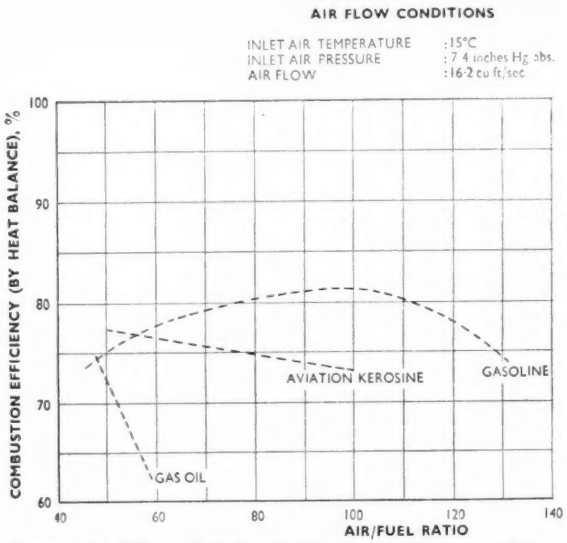


FIGURE 5.—Effect of fuel volatility on combustion efficiency (combustion chamber B) at high altitude idling conditions, and with spill atomiser at low input flow.

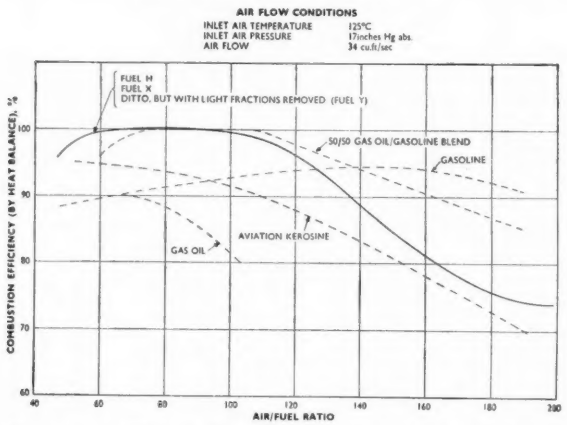


FIGURE 7. Effect of fuel volatility on combustion efficiency (combustion chamber B) at high altitude cruising conditions, and with spill atomiser at low input flow.

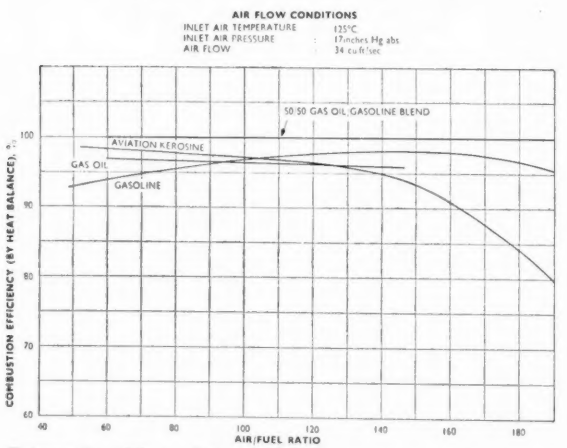


FIGURE 8. Effect of fuel volatility on combustion efficiency (combustion chamber B) at high altitude cruising conditions, and with spill atomiser at high input flow.

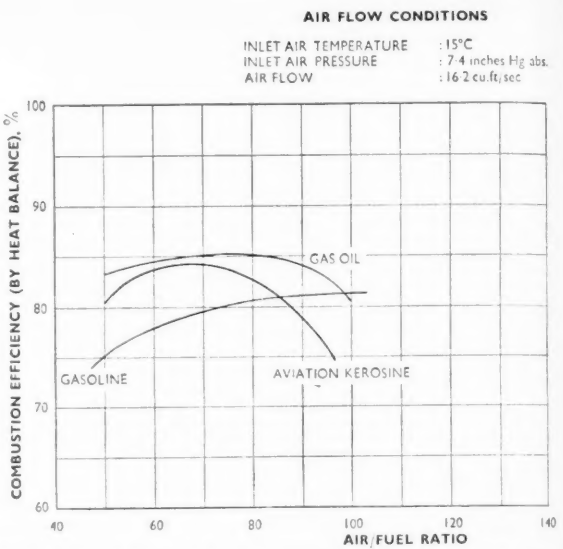


FIGURE 6. Effect of fuel volatility on combustion efficiency (combustion chamber B) at high altitude idling conditions, and with spill atomiser at high input flow.

shown that changes of cone angle can have their own effects on performance but, for the changes experienced here due to change of input, output or fuel type, the effects are unimportant compared with those of degree of fuel atomisation, and certainly can be ignored for the purposes of this paper.

Further study of Figs. 5 to 8 shows that in every case the combustion efficiency with gasoline attained a maximum at weaker air/fuel ratios than in the normal cruising region (ca. 75/1), whereas with the less volatile fuels, gas oil and kerosine, efficiency maxima occurred at richer mixtures. These results indicate that the rapidity of vaporisation with the volatile gasoline prevented its proper distribution throughout the combustion zone and created, particularly at the richer air/fuel ratios, local over-rich zones in the mixture which burned inefficiently. Clearly, relatively slight modifications to the chamber, designed to cause the combustion zone as a whole to run rather weaker at the same overall (cruise) air/fuel ratio, would improve performance with gasoline. Alternatively some redistribution of the air supply to the combustion zone to prevent over-rich regions would effect an improvement; thus if the central regions were over-enriched by rapid vaporisation, extra air introduced there would be a solution.

(*ii*) *Vapour-Injection-Type Combustion Chamber*

Figure 10 shows that under certain conditions with this type of chamber, as with spray types, only small performance differences between fuels were found. (The gas oil gave low performance in this case merely because the vaporiser was inadequate for this involatile fuel, for which it was not designed). Figs. 11 to 14, however, show that under lower pressure conditions performance is generally rather lower and considerable differences between fuels (including practical types) can occur, although fuel vaporisation is complete. Following

these results it was found that different vaporiser types had marked effects on fuel performance and fuel performance differences, as shown for two fuels in Figs. 15 and 16. It should be noted that for the results given in Figs. 15 and 16 vaporisation was complete in each case; the performance differences were due, not to inadequate vaporising performance, but to the different air patterns and fuel distributions in the combustion zone resulting from the use of the different vaporiser assemblies. It follows, from the different magnitudes of the effects on different fuels, that the vaporiser changes altered considerably the sensitivity of the chamber to fuel properties. It is clear, therefore, that as with the spray-injection type, component design can affect not only the level of chamber performance but also, the performance differences between fuels.

A further point, as indicated in Fig. 17 (compare with Fig. 14), is that increased throughput can reduce the performance level of a chamber and increase fuel performance differences. This illustrates the need to guard against such possible effects in newly-designed chambers required for duty under more arduous conditions than in the past, and which may therefore be potentially more sensitive to the effects of fuel type on performance.

Four main conclusions can be drawn from the results with spray-and vapour-injection type combustion chambers:

(*i*) Where combustion efficiency is poor it can frequently be raised considerably, and differences between fuels largely eliminated, by improving the quality of fuel atomisation; this will not necessarily be true for very volatile fuels, for which a lower degree of atomisation will suffice for optimum performance.

(*ii*) Adverse fuel distribution effects due, for example, to over-rapid vaporisation with very volatile fuels, can be overcome by relatively slight modifications to the combustion chamber itself.

(*iii*) Combustion chamber design can considerably alter the sensitivity of chamber performance to fuel type. This should be borne in mind when new chambers are designed for use under possibly more arduous conditions than in the past.

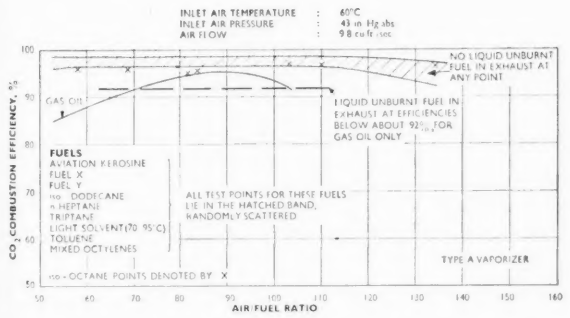

INLET AIR TEMPERATURE : 60°C
INLET AIR PRESSURE : 43 in. Hg abs
AIR FLOW : 9·8 cu ft/sec
NO LIQUID UNBURNT FUEL IN EXHAUST AT ANY POINT
GAS OIL
LIQUID UNBURNT FUEL IN EXHAUST AT EFFICIENCIES BELOW ABOUT 92% FOR GAS OIL ONLY
FUELS
AVIATION KEROSINE
FUEL X
FUEL Y
iso-DODECANE
n-HEPTANE
TRIPTANE
LIGHT SOLVENT (70 95°C)
TOLUENE
MIXED OCTYLENES
ALL TEST POINTS FOR THESE FUELS LIE IN THE HATCHED BAND, RANDOMLY SCATTERED
TYPE A VAPORIZER
iso-OCTANE POINTS DENOTED BY X
CO COMBUSTION EFFICIENCY, %
AIR FUEL RATIO

FIGURE 10. Effects of fuel type on combustion efficiency—medium altitude, normal cruising air flow (vapour-injection type combustion chamber).

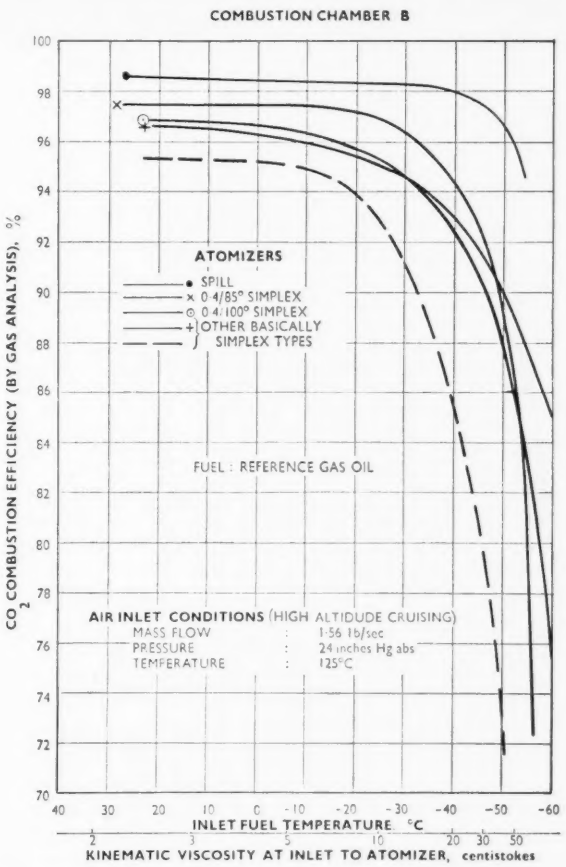

COMBUSTION CHAMBER B
ATOMIZERS
SPILL
0·4/85° SIMPLEX
0·4/100° SIMPLEX
OTHER BASICALLY SIMPLEX TYPES
FUEL : REFERENCE GAS OIL
AIR INLET CONDITIONS (HIGH ALTITUDE CRUISING)
MASS FLOW : 1·56 lb/sec
PRESSURE : 24 inches Hg abs
TEMPERATURE : 125°C
CO COMBUSTION EFFICIENCY (BY GAS ANALYSIS), %
INLET FUEL TEMPERATURE °C
KINEMATIC VISCOSITY AT INLET TO ATOMIZER, centistokes

FIGURE 9. Effects of fuel temperature and viscosity upon combustion efficiency at an air/fuel ratio of 75:1.

(*iv*) From the point of view of combustion efficiency, there is no need to impose limits on fuel distillation characteristics, at least over the range covering gasoline to gas oil, in order to allow satisfactory performance, which can now easily be obtained by good equipment design. (Evidence not presented here suggests successful use of even heavier fuels than gas oil.)

2. Combustion stability

(*i*) *Spray-Injection Type Combustion Chambers*

With spray-injection chambers it has been found that fuel physical properties can markedly affect the weak combustion limits, the magnitude and sense of the effects depending upon the air/fuel mixing conditions in the chamber. Typical results for practical and experimental fuels are given in Fig. 18, obtained on combustion chamber B at cruising air flow conditions at two altitudes. Fig. 18 shows that, at the higher altitude conditions, with the higher atomisation quality (high input flow to spill atomiser) extinction air/fuel ratios deteriorated from about 250/1 with the more volatile fuels (gasolines with low 10 per cent. distillation temperatures) to about 150/1 with the less volatile fuels (in the gas oil region). With the lower atomisation quality,

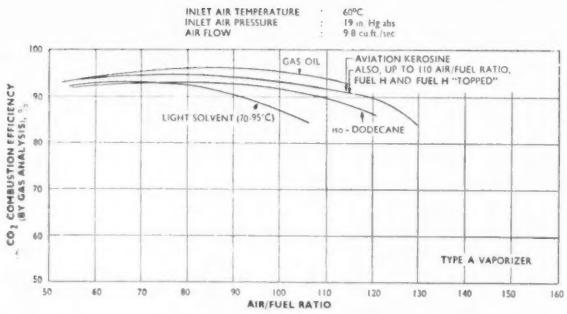

INLET AIR TEMPERATURE : 60°C
INLET AIR PRESSURE : 19 in. Hg abs
AIR FLOW : 9·8 cu.ft./sec
GAS OIL
AVIATION KEROSINE
ALSO, UP TO 110 AIR/FUEL RATIO, FUEL H AND FUEL H "TOPPED"
LIGHT SOLVENT (70-95°C)
iso - DODECANE
TYPE A VAPORIZER
CO2 COMBUSTION EFFICIENCY (BY GAS ANALYSIS), %
AIR/FUEL RATIO

FIGURE 11. Effects on combustion efficiency of using fuels of widely different volatility at high altitude cruising conditions (vapour-injection type combustion chamber).

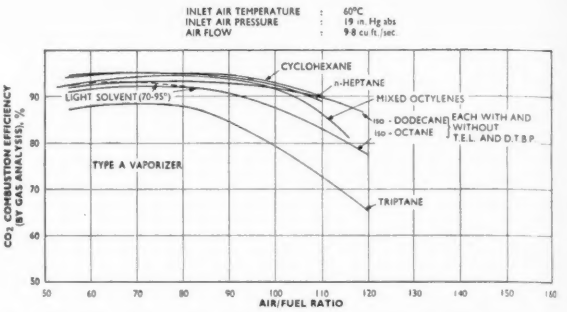


FIGURE 12. Effects on combustion efficiency of using fuels of different chemical properties, at high altitude cruising conditions (vapour-injection combustion chamber).

however, weak extinction with the volatile fuels was very much better than with better atomisation, although as volatility decreased performance deteriorated rapidly until, with the least volatile fuel tested, it was inferior to that with good atomisation. Similar trends were observed at lower altitude conditions.

An explanation for these results is suggested as follows:

When the fuel droplets are large, flame propagation can be considered as from one droplet to another, each droplet, when burning, having its own separate flame which can ignite other droplets. Under such conditions fuel volatility can be important, since more volatile droplets will have greater volumes of vapour surrounding them and, as a result, greater radii at which ignition can occur; thus flame propagation may be easier, and combustion limits wider, when fuels of higher volatility are used. On the other hand, too great a fuel volatility may give too rapid an evolution of vapour and thus completely evaporate some of the smaller droplets. This vapour, in mixing rapidly into the air, may result in local relatively homogeneous mixtures which are too weak (or too rich) to burn; thus flame propagation would be hindered and combustion limits narrowed, as with more homogeneous mixtures.

When fuel atomisation is improved, the dispersion of fine fuel droplets in air will have combustion properties approaching those of an air/vapour mixture more and more closely as droplet size is reduced; when this happens, the actual combustion limits will depend upon the degree of homogeneity, but for a similar broad distribution of fuel the mixture will be locally more homogeneous and combustion limits will tend to be narrower.

When the foregoing considerations are applied to a combustion chamber, the influence of atomisation and fuel volatility can readily be understood, including the existence of an optimum volatility which has been observed under some conditions. A further factor influencing weak limits is the effect on droplet life of degree of atomisation, and to a lesser extent, of fuel volatility. Increased atomisation implies shorter-lived droplets and therefore fewer burning droplets recirculated to ignite incoming fuel; this may be a further cause of poorer weak limits as atomisation is improved.

Summarising, therefore, it can be said that fuel properties can markedly affect combustion weak limits, the more volatile fuels giving wider limits. The effect of fuel atomisation can also be of great importance, however, and offers the possibility of improved combustion limits if it is matched with fuel volatility by suitable design or control.

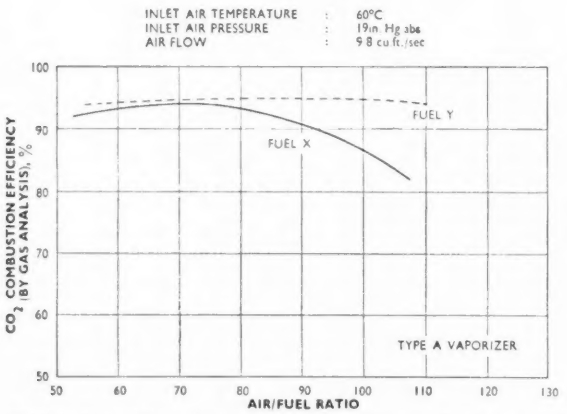

INLET AIR TEMPERATURE : 60°C
INLET AIR PRESSURE : 19 in. Hg abs
AIR FLOW : 9·8 cu.ft./sec
FUEL Y
FUEL X
TYPE A VAPORIZER
CO2 COMBUSTION EFFICIENCY (BY GAS ANALYSIS), %
AIR/FUEL RATIO

FIGURE 13. Effects on combustion efficiency of using a fuel with and without its light fractions, at high altitude cruising conditions (vapour-injection combustion chamber).

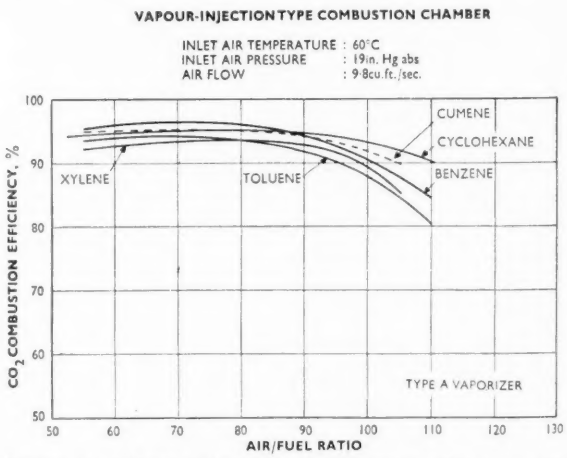


FIGURE 14. Effects of fuel type on combustion efficiency—high altitude cruising conditions. Aromatic fuels.

(ii) Vapour-Injection Type Chambers

Figure 19 shows typical weak-limit curves for a vapour-injection combustion system using three fuels of widely different physical properties. Clearly the most volatile fuel (the light solvent) gave the best performance, the other fuels performing in order of volatility. The effect of inlet air temperature on performance had different effects with the different fuels: the weak limits of the light solvent were worsened, whereas for the less volatile fuels they were improved. The explanation is that, whereas for the less volatile fuels increased air temperature increased the proportion of fuel vaporised, and hence the amount of vapour available for combustion, thus improving performance, with the light solvent vaporisation was already complete at the lower temperature, and the increased air temperature adversely altered the air/fuel mixture distribution to give slightly inferior performance. Other evidence indicated that the effects of inlet air temperature were reversed for each fuel at lower air pressures. Fig. 20 shows, for constant cruising air throughput, the beneficial effect of increased inlet air pressure (*i.e.* lower altitude) on performance, and its influence on the effects of inlet air temperature.

It was found that in most cases fuel chemical structure had relatively little effect on "blow-out" performance, and the effects of fuel physical properties (for experimental and practical fuels) could be represented adequately by the 50 per cent. distillation temperature, as shown in Fig. 21; it may be noted, however, that the performance of xylene (aromatic) and the light solvent (140-165°C.—largely paraffinic) were lower than would be expected on this basis, suggesting that performance could also be affected by factors in addition to distillation characteristics, dependent possibly more directly on fuel chemical structure.

Figure 22 shows similar curves with the same vaporising device appropriate to Figs. 19 to 21, but in a surface condition more conducive to the effective transfer of vaporising heat to the fuel; a marked improvement in performance, particularly at the lower inlet air pressures is apparent; performance differences between fuels are also reduced and the generally beneficial effect of increased inlet air temperature is also

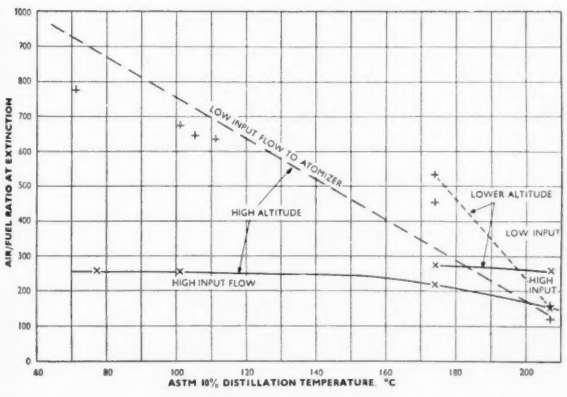


FIGURE 18. The weak extinction limits of combustion chamber B, employing a spill atomiser, at cruising air flow conditions.

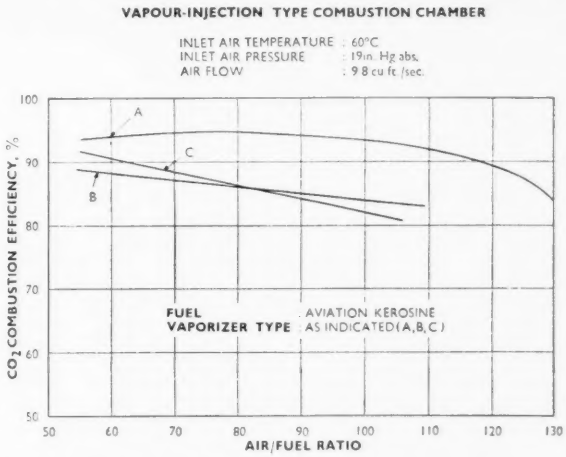

VAPOUR-INJECTION TYPE COMBUSTION CHAMBER
INLET AIR TEMPERATURE : 60°C
INLET AIR PRESSURE : 19in. Hg abs.
AIR FLOW : 9·8 cu ft /sec.
A
C
B
FUEL : AVIATION KEROSINE
VAPORIZER TYPE : AS INDICATED (A, B, C)
CO2 COMBUSTION EFFICIENCY, %
AIR/FUEL RATIO

FIGURE 15. Effect of vaporiser type on combustion efficiency—high altitude cruising conditions.

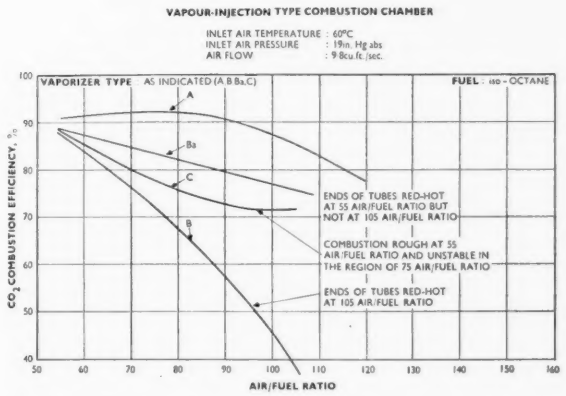

VAPOUR-INJECTION TYPE COMBUSTION CHAMBER
INLET AIR TEMPERATURE : 60°C
INLET AIR PRESSURE : 19in. Hg abs
AIR FLOW : 9·8cu.ft./sec.
VAPORIZER TYPE AS INDICATED (A B Ba C)
FUEL : 100 - OCTANE
A
Ba
C
B
ENDS OF TUBES RED-HOT AT 55 AIR/FUEL RATIO BUT NOT AT 105 AIR/FUEL RATIO
COMBUSTION ROUGH AT 55 AIR/FUEL RATIO AND UNSTABLE IN THE REGION OF 75 AIR/FUEL RATIO
ENDS OF TUBES RED-HOT AT 105 AIR/FUEL RATIO
CO2 COMBUSTION EFFICIENCY, %
AIR/FUEL RATIO

FIGURE 16. Effect of vaporiser type on combustion efficiency—high altitude cruising conditions.

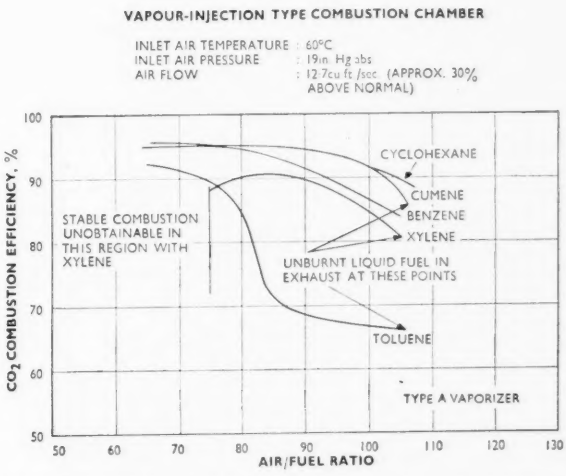

VAPOUR-INJECTION TYPE COMBUSTION CHAMBER
INLET AIR TEMPERATURE : 60°C
INLET AIR PRESSURE : 19in. Hg abs
AIR FLOW : 12·7cu ft /sec (APPROX. 30% ABOVE NORMAL)
CYCLOHEXANE
CUMENE
BENZENE
XYLENE
STABLE COMBUSTION UNOBTAINABLE IN THIS REGION WITH XYLENE
UNBURNT LIQUID FUEL IN EXHAUST AT THESE POINTS
TOLUENE
TYPE A VAPORIZER
CO2 COMBUSTION EFFICIENCY, %
AIR/FUEL RATIO

FIGURE 17. Effects of fuel type on combustion efficiency—high altitude cruising conditions, increased throughput.

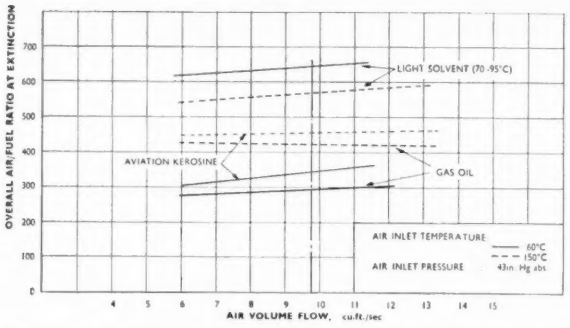


FIGURE 19. Effect of fuel distillation characteristics on weak limits of combustion at two air inlet temperatures (vapour-injection type combustion chamber).

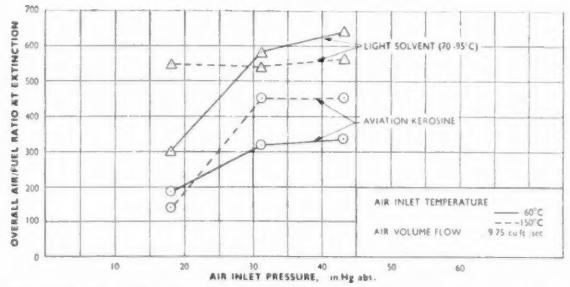


FIGURE 20. Effect of air inlet pressure on weak limits of combustion (vapour-injection type combustion chamber)

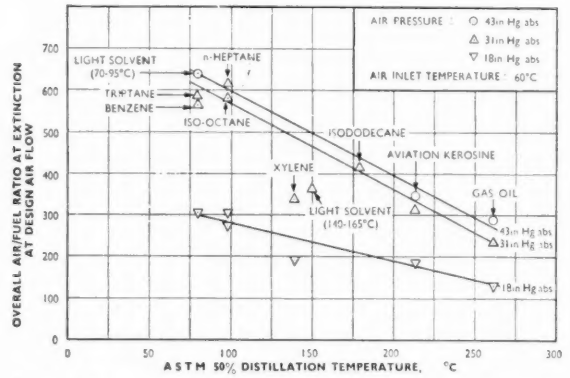


FIGURE 21. Effect of A.S.T.M. 50 per cent. distillation temperature on performance (vapour-injection type combustion chamber).

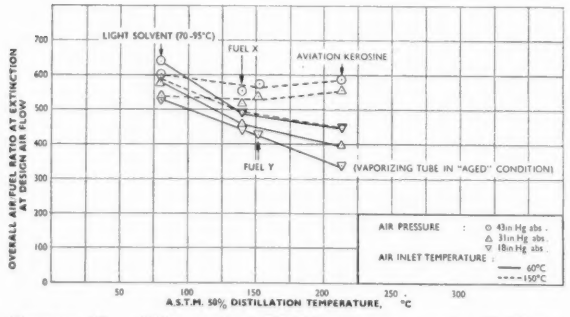


FIGURE 22. Effect of A.S.T.M. 50 per cent. distillation temperature on performance.

shown. Fig. 23 illustrates the marked improvement in performance which was secured by using a different geometric design of vaporising device; the advantage here was probably gained by a combination of increased vaporising effectiveness and better air flow pattern.

In summary, therefore, it can be said that, as for the spray-injection type, the weak limit performance of vapour-injection type chambers can be markedly affected by the physical properties of the fuel—in general the lighter the fuel the better the performance. The important effects of change in vaporiser effectiveness or geometrical design have also been shown, again clearly illustrating the effectiveness of good design in mitigating possible adverse effects of fuel properties.

3. Ease of Ignition

The two main methods of ignition for combustion chambers in current use are:

(*a*) direct electrical ignition of the main fuel spray by a high-tension spray igniter, or by low-tension high-energy surface discharge igniter, and (*b*) electrical ignition of a subsidiary fuel spray which in turn ignites the main spray, *i.e.* the torch igniter. The initial ignition problems of (*a*) and (*b*) are similar; the torch igniter can frequently be regarded as a subsidiary combustion chamber operating under a more favourable range of conditions than does the main chamber.

Apart from the nature of the electrical ignition source other factors which can influence the ease of ignition of a fuel spray are:

(*i*) degree of fuel atomisation under ignition conditions
(*ii*) fuel volatility
(*iii*) relative locations of ignition source and fuel spray
(*iv*) air temperature, pressure and flow conditions in the chamber
(*v*) the intensity and discharge characteristics of the ignition spark.

Fuel characteristics can influence (*i*) and (*ii*) directly and the other factors are likely to affect the relative starting performance of different fuels. For example, the influence of atomisation and fuel volatility is likely to be less important when a more effective ignition

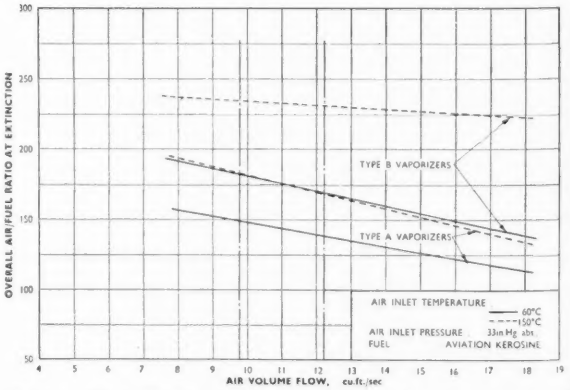


FIGURE 23. Weak combustion limits using two types of vaporiser at two air inlet temperatures.

source is used. This point is well illustrated in Fig. 24; a chamber was used under standardised operating conditions, with experimental and practical fuels, the criterion being the minimum fuel pressure (Simplex atomiser) at which ignition reliably occurred. The curves show clearly that the more volatile fuels (lower 10 per cent. recovery temperature) gave better performance with either system of ignition, but also that the influence of fuel volatility was much smaller when the more effective high-energy low-tension surface-discharge ignition system was used instead of the (then) standard high-tension system.

Figure 25 shows the relative performance of two fuels under engine windmilling conditions, at a moderate aircraft forward speed, using the surface discharge ignition system. It should be noted that igniter position can have a large effect on ignition performance; in these tests the igniter was not necessarily in the optimum position for the particular chamber. The fuels used were SR.312 (a reference aviation kerosine conforming substantially to specification D.ENG.R.D.2482—approximately U.S.JP-1) and Fuel J (a more volatile fuel conforming to specification D.ENG.R.D.2486—approximately U.S.JP-4); the latter had a Reid Vapour Pressure of 2·7 lb./in.^{2} at 100°F. It will be observed that with the more volatile fuel the weak ignition limits are weaker, and the rich ignition limits are also weaker over the greatest part of the air pressure (altitude) range. It is clear from Fig. 25 that the ease of ignition of a particular engine with these fuels will depend upon the air/fuel ratio, *i.e.* the fuel flow (for given windmilling conditions) supplied to the combustion chambers. Too low a flow (curve A, for example) would mean that ignition would be easier with the more volatile fuel, while with too high a flow (for example, curve B) the reverse would hold; the correct flow is indicated by curve C, although for safety it would be desirable to improve chamber design so as to widen the ignition limits and render the fuel flow less critical.

It is also clear from Fig. 25 that the chamber could be ignited at lower pressures (higher altitudes) when using the more volatile fuel.

It was also found from other tests that inlet air temperature (over the range −23°C. to +18°C.) had little effect on ignition. The chemical composition of the fuel, as altered by changing its aromatic content from 12·5 per cent. *w* to 38 per cent. *w*, with unchanged volatility, also had no effects. The main factor, other than fuel, which affected performance was the air mass flow through the chamber, air pressure having relatively little effect, as illustrated in Fig. 26; the minimum fuel pressure (Simplex atomiser) for reliable ignition to occur was used as the measure of performance in this case.

It is clear from the foregoing that although fuel volatility can have important effects on ignition, these effects can be greatly reduced by using efficient ignition equipment suitably disposed. Further, by ensuring that the fuel system supplies the correct amount of fuel to the engine under starting conditions, ease of ignition will in practice be unaffected by volatility, except in so far as with a particular chamber the more volatile fuel may allow ignition at rather higher altitudes; the limiting

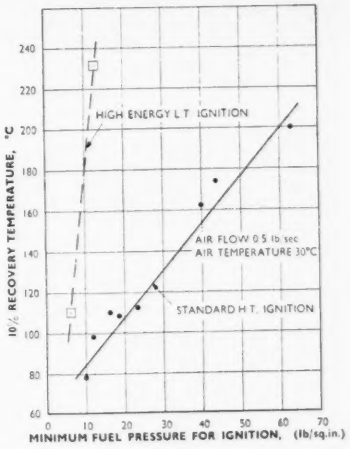

HIGH ENERGY L.T. IGNITION
AIR FLOW 0·5 lb/sec
AIR TEMPERATURE 30°C
STANDARD H.T. IGNITION
10% RECOVERY TEMPERATURE, °C
MINIMUM FUEL PRESSURE FOR IGNITION, (lb/sq.in.)

FIGURE 24. Effect of fuel volatility on starting characteristics (combustion chamber A).

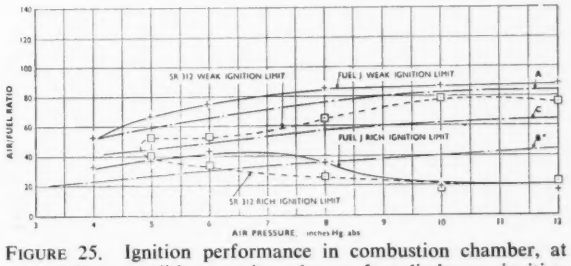

SR 312 WEAK IGNITION LIMIT
FUEL J WEAK IGNITION LIMIT
FUEL J RICH IGNITION LIMIT
SR 312 RICH IGNITION LIMIT
AIR/FUEL RATIO
AIR PRESSURE, inches Hg abs

FIGURE 25. Ignition performance in combustion chamber, at windmilling conditions, using the surface-discharge ignition system.

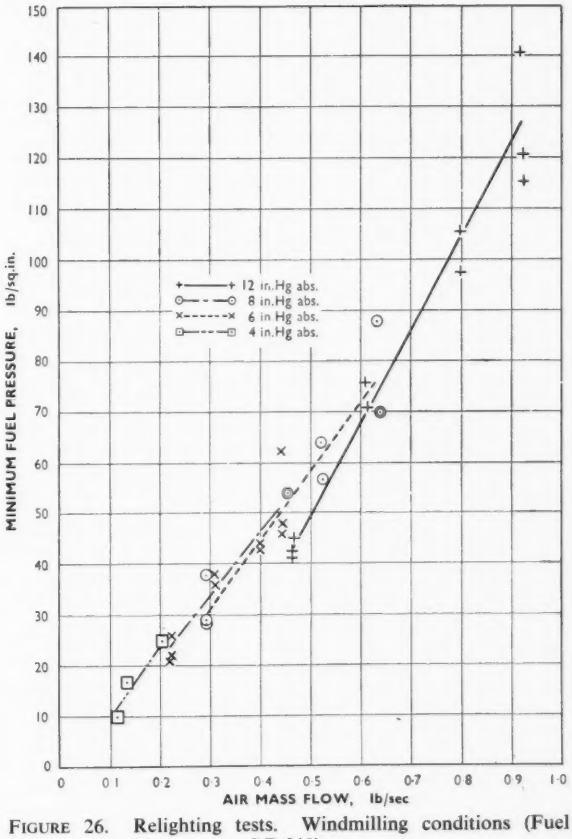


FIGURE 26. Relighting tests. Windmilling conditions (Fuel S.R.312).

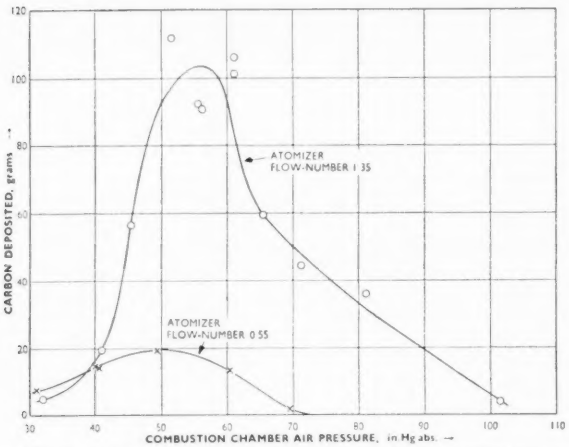


FIGURE 27. Effect of pressure and atomiser flow-number on deposits.

height with the least volatile fuel is largely a matter of correct chamber design, to ensure that it is adequate for operational purposes.

It is considered that with these conditions, and as a result of improved chamber design generally, aero gas turbine combustion chambers need not, in practice, require fuels of specified minimum vapour pressure to ensure reliable ignition under likely starting conditions; this justifies the existing exclusion of such a minimum requirement from the present D.ENG.R.D.2486 specification.

4. Deposits

Deposits in aircraft gas turbine combustion chambers are mainly of a carbonaceous nature and are built up, usually, by the condensation of burning materials in the flame on to relatively cool surfaces in close proximity to the flame. Little trouble has been experienced from ash deposits since ash contents are generally negligible in distillate fuels. The deposits discussed here can be divided conveniently into two main classes, namely those which occur in the main body of the combustion chamber, and those which form on the atomiser.

(i) *Deposits in the Body of the Chamber*

Carbonaceous deposits in combustion chambers are undesirable because of two main effects. Their presence upsets air flow and can upset performance; they can also cause severe temperature gradients in the flame-tube wall material, resulting in short life due to cracking and buckling. It should be said immediately that serious trouble from this source is not encountered with contemporary British combustion chambers; deposits which were troublesome in earlier models have virtually been eliminated by improved design and sound development. However, the possibility exists of a recurrence of the trouble with increased air pressures and more highly loaded chambers.

Figure 27 illustrates, for example, the manner in which increased air pressure can affect deposits in spray-injection-type chambers and shows also the beneficial effect of improved fuel atomisation in reducing them. In this particular case maximum deposit occurred at a relatively low pressure, well below the highest used practically, and even so no serious deposits occurred in practice. For a chamber of different design, however, the pessimum pressure might lie above the highest used at present, and future operation at higher pressures, therefore, might bring trouble. The effects of fuel properties on deposits have been investigated, using standard full-scale chambers and also small-scale rig combustion tubes. Despite the wide range of fuels investigated, it was not found possible to assess satisfactorily the relative importance of the separate effects of fuel features such as distillation characteristics, viscosity and chemical structure, but it was found that, for spray-injection combustion chambers, the specific gravity of the fuel can be used to estimate fuel performance in this respect sufficiently accurately for most practical purposes.

Figure 28 shows the correlation with fuel specific gravity. It was also found that there was a similar, but slightly less satisfactory correlation with carbon/hydrogen ratio.

It should be noted that for test purposes artificial running conditions were used, in order to accelerate deposit formation greatly and to enable results to be obtained reasonably quickly. The amounts of carbon plotted in Figs. 27 and 28 were deposited in one hour under these artificial conditions, and give only a relative, not an absolute indication of deposit weights which might be obtained under practical operating conditions (which would be negligible in contemporary chambers).

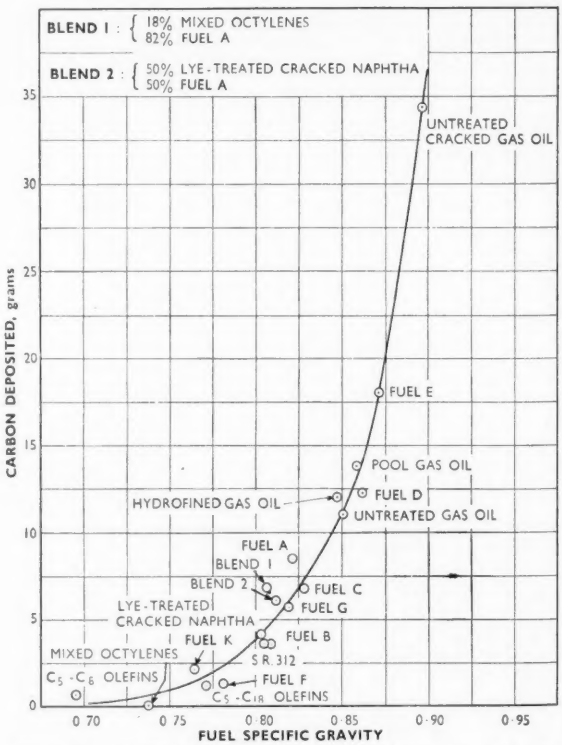


FIGURE 28. Correlation between carbon deposition and fuel specific gravity.

It has been established that sulphur content (up to one per cent. *w*) and gum content (944 mg/100 ml) of the fuel have no significant effects on deposits.

(*ii*) *Deposits on the Atomiser*

Since the introduction of wide-cut fuels of the JP-3 and JP-4 types, new problems have arisen in connection with the much greater amounts of carbonaceous material deposited on the tips of the atomiser air shrouds when such fuels are used. The air shrouds have generally continued to keep the orifice plates relatively clear of deposit, but the deposits on the shrouds themselves have seriously interfered with the fuel sprays in some engines, thereby upsetting combustion and causing buckled combustion chambers.

This problem is still under investigation and it is possible to give only a few broad conclusions at this stage.

Figure 29 shows typical deposits with two fuels, Fuel H (a reference JP-3 type fuel) and a reference aviation kerosine (approximately JP-1); these deposits were obtained under test conditions conducive to deposit formation and known to simulate engine conditions in respect of order of fuel deposit rating. Clearly the JP-3 type fuel gives deposits much more likely to foul fuel sprays than those from aviation kerosine, which are much more compact.

While higher-boiling fuel-fractions give the greater contributions to deposit weight, it is not, however, weight *per se* which is important but the tendency of the deposit to foul the fuel spray and it has been found that the light fuel-fractions can affect the nature of the deposit and hence its fouling tendency also.

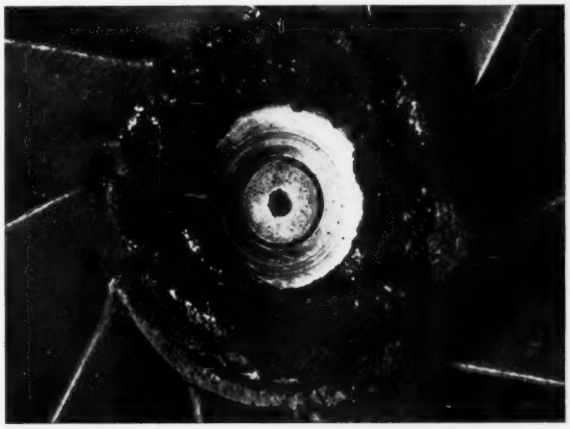
Correlations of spray-fouling tendencies of fuels with fuel properties are still under investigation, but broadly it can be said that the heavier the fuel the heavier the deposit and the more likely the deposit to foul the fuel spray.

To illustrate the possible effects of the amount of air through the air shroud, tests were made with this reduced by 30 per cent. and 60 per cent. approximately from its original value. The effects were virtually to eliminate the deposits. The result as it stands applies only to the particular engine and particular operating conditions, but it demonstrates clearly the possibility of the virtual elimination of serious deposits by slight local air flow changes given by small design modifications.

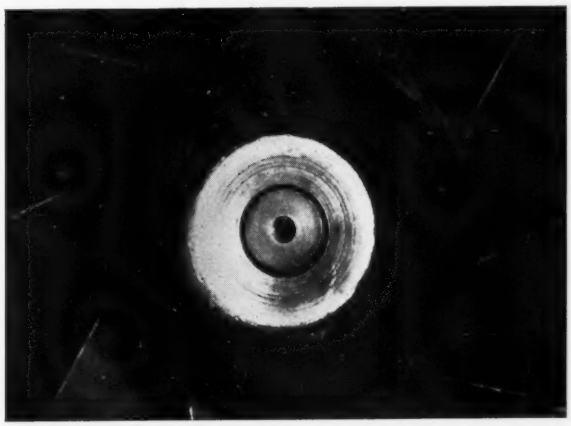
(*iii*) *Vapour-Injection Type Combustion Chambers*

Tests made on well-designed vapour-injection type chambers have shown that these are not likely to be affected by serious carbonaceous deposits; this is owing in large measure to well-directed preventative local air streams over relevant surfaces. Under artificial conditions it is possible to obtain deposits, however, and when this is done it is found that the same general conclusions hold as for the spray-injection types—*i.e.* the heavier fuels tend to give the heavier and more troublesome deposits.

Summarising, it can be said that fuel properties can affect carbonaceous deposits formed in combustion chambers—broadly the heavier the fuel the heavier and more troublesome the deposits are likely to be. The large effect of good design, however, in virtually eliminating troublesome deposits has been adequately demonstrated.



Heavy deposit with Fuel H, after 7 hours under the standard rig conditions.



Light deposit with aviation kerosine (to D.Eng. R.D.2482) after 7 hours under the standard rig conditions. No evidence of fuel-spray interference.

FIGURE 29. Deposits obtained on the atomiser air shroud tip in a spray-type combustion chamber.

5. Exhaust Temperature Variation

The achievement of a satisfactory exhaust temperature variation from a combustion chamber is of obvious importance in attaining maximum life of turbine nozzle guide vanes and rotor blades. To ascertain possible effects of fuel on this factor, exhaust temperature traverses obtained from two spray-injection type combustion chambers when burning fuels of substantially different volatilities were analysed. Fig. 30 shows that the effects of using a very volatile fuel, the light solvent (70-95°C.), instead of the much less volatile aviation kerosine, in combustion chamber A were insignificant. The effects of varying atomisation quality, by varying atomiser size, were also, on the whole, insignificant. An exception occurred at one point where, with the finer atomisation and the more volatile fuel, the combustion quality unexpectedly changed because of the very high

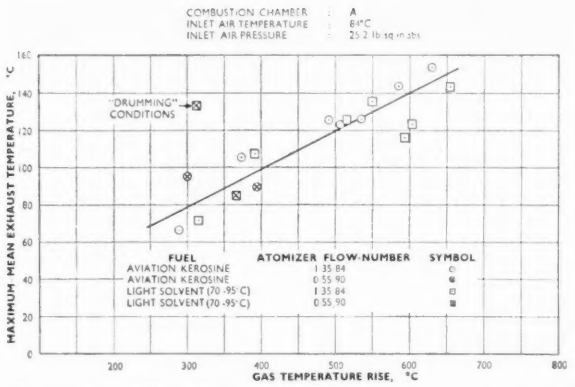


FIGURE 30. Effect of fuel volatility and degree of atomisation on exhaust temperature variation.

evaporation rate, as discussed later, and a "drumming" sound was heard, the flame shape altered and the temperature distribution was markedly affected, as indicated.

Figure 31 shows results applicable to combustion chamber B, which was of the same basic design as A, but of much smaller length/diameter ratio; clearly the light gasoline gave a much greater temperature variation than did the less volatile aviation kerosine, in contrast with the results obtained in chamber A. A similar effect was noted at idling conditions. The use of different degrees of fuel atomisation, as determined by input flow to the spill atomiser, had no significant effects on exhaust temperature variation with either fuel.

The results obtained in chamber B demonstrate that change in fuel volatility can strongly affect the combustion pattern in the combustion zone; in this case the use of more volatile fuel, giving more rapid vaporisation, had adverse effects because of reduced penetration and consequent mal-distribution of fuel vapour in the combustion zone. This is consistent with the evidence, presented earlier in connection with combustion efficiency, showing the gasoline to give poorer efficiency

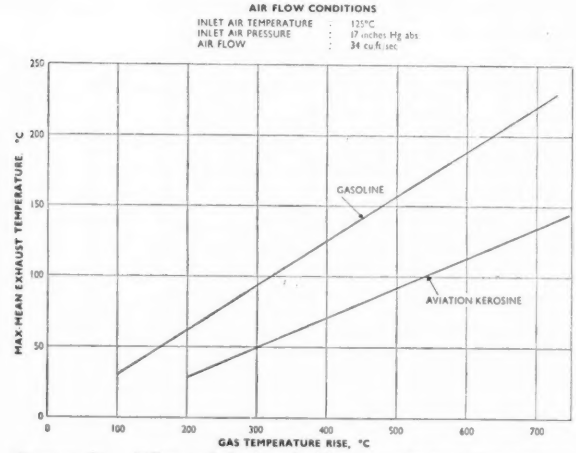

AIR FLOW CONDITIONS
INLET AIR TEMPERATURE : 125°C
INLET AIR PRESSURE : 17 inches Hg abs
AIR FLOW : 34 cu ft/sec
MAX MEAN EXHAUST TEMPERATURE °C
GASOLINE
AVIATION KEROSINE
GAS TEMPERATURE RISE, °C

FIGURE 31. Effect of fuel volatility on exhaust temperature variation (combustion chamber B with spill atomiser at all input flows, at high altitude cruising conditions).

than the less volatile aviation kerosine under the same conditions; this was attributed to over-rich regions in the combustion zone.

Clearly there was a possibility of change in temperature variation as fuel volatility was changed, in both chambers. It is considered, however, that the greater relative length of the mixing paths and a greater influence of dilution air mixing in chamber A were the effective causes of a greater (virtually complete) suppression of an ultimate effect on exhaust temperature variation in this chamber.

Any adverse effects on exhaust temperature variation due to the use of fuels of different volatility would, by virtue of the mechanism of the effect, probably have effects on combustion efficiency also. If the effects on efficiency and general performance were also adverse, both effects would have to be countered first by modifications to the combustion zone. Thus if the adverse effects on combustion efficiency, for example, were caused by using a more volatile fuel, suggesting over-rich fuel/air mixtures in the centre, an increased air supply to this region, or even a general weakening of the combustion zone, as indicated earlier, would probably effect a cure. When sufficient restoration of combustion efficiency occurred, final correction of exhaust temperature variation should be made by adjustments to the dilution air mixing.

The use of fuels of different volatility can therefore affect the combustion pattern in the combustion zone in such a way that marked changes in exhaust temperature variation can occur. Adverse effects due to this cause can be countered by design action, in some cases for all likely fuels, and in all cases for specific fuels.

6. Smooth Combustion

No occurrence of phenomena analogous to detonation in reciprocating engines has yet been established for gas turbine combustion chambers. A phenomenon that can cause trouble, however, is that of "rough" running, which often manifests itself as a continuous or intermittent rumble or as a beating sound, sometimes called "motor-boating." This phenomenon can cause engine trouble, and it is of interest to know how it can be affected by fuel characteristics. The results of relevant observations (incidental to other work) are illustrated in Fig. 32, which shows areas of "roughness" as indicated by manometer fluctuations, for three fuels and two atomiser sizes; the roughness was characterised, apart from rumbling and manometer fluctuations, by irregular changes in flame shape and colour accompanied by changes in noise level.

Figure 32 shows that, with the coarser (1·35/84) atomiser, the change from aviation kerosine to the more volatile fuel (K) had little effect on the size of the roughness area, although its boundaries were shifted. When the finer (0·55/90) atomiser was used the regions of roughness were greatly increased for the more volatile fuel; a reversion to a rather less volatile fuel (F) had the effect of reducing roughness area. The adverse effects of increased degree of fuel atomisation and greater fuel volatility were considered to be due to decreased penetration (caused by shorter droplet life) of fuel in the

combustion zone, leading to rich or over-rich fuel/air ratios locally in the first instance.

The cure for such troubles lies in improved design, on the line suggested already for improving combustion efficiency and exhaust temperature variation when highly volatile fuels are used, *i.e.* some modification to air pattern in the combustion zone, or even the mere weakening of this zone.

7. General Conclusions

Aero gas turbine performance, as assessed by various standards, can be affected significantly by fuel characteristics. These effects are in most cases aggravated by deficiencies in combustion systems, such as poor fuel atomisers, indifferent ignition equipment and inferior flame-tube component design. These deficiencies are not in most cases inherent in combustion systems. Thus, for example, whereas spark-ignition piston engines are largely restricted to the use of gasoline because of otherwise practically intractable starting, warm-up and distributional problems, and also to the use of given grades on account of knock difficulties, this sort of situation, at least for a very wide distillate fuel range, does not exist with the aero gas turbine; here the problems are usually soluble by design action. Therefore, although some current engines may be sensitive in some respects to fuel characteristics, and may require fuel quality restrictions of some sort for performance reasons (for example a minimum vapour pressure to permit reliable ignition), this is probably because they are unnecessarily deficient in some way. Fuel quality restrictions almost inevitably result in higher fuel costs and lower availability—both serious disadvantages, particularly in emergency.

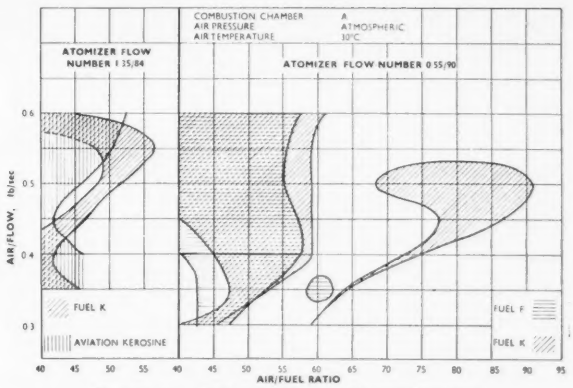


FIGURE 32. Regions of unstable combustion.

The work described has demonstrated adequately that the effects of fuel properties on performance can be so mitigated (or even eliminated) by good design action that adverse effects on fuel costs, or availability due to this possible cause, need not occur.

ACKNOWLEDGMENT

The author wishes to thank the Ministry of Supply, on whose behalf much of the work described in this paper was done, and the Directors of the Shell Petroleum Co. Ltd. for permission to publish the results given in this paper; also members of the Thornton staff who have given advice in its preparation.

Gusts and their Measurement*

by

J. TAYLOR, M.A., A.F.R.Ae.S.

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1. Introduction

From the earliest days of flying, gusts have been a problem for aircraft. In the very early flights aircraft were flown only when it was nearly dead calm and few gusts were met. Later on and, in fact, almost up to the Second World War, flying was greatly restricted by the ground and air conditions at the aerodrome. This meant that there had to be fairly good visibility and that the grass aerodrome must not be unduly softened by water. Since the war, aircraft have been flown with much greater regularity. The aerodromes are better and there is virtually no limitation due to the conditions of the runways. Also, it is possible to use radio aids to such an extent that visibility at the aerodrome is of far less significance. Nowadays fog is probably the only reason for stopping an aircraft either taking off or landing; flights at night are commonplace. Taking all these conditions into consideration it may be deduced that aircraft are now hitting far more gusts than they were fifteen years ago. They fly faster, more often, and in worse weather conditions.

The interest in gusts, as affecting aircraft, is in those gusts that are actually met and not in the meteorological conditions of the atmosphere. Aircraft on normal operation will miss extremely bad weather conditions most of the time, but not always. If we were interested in the meteorological conditions of the atmosphere, it is highly unlikely that we could determine them for it would be far too dangerous to fly aircraft completely indiscriminately, both from the risk of hitting mountains and of crashing on take-off and landing.

When gusts are recorded on aircraft on normal operational duties, statistical information is obtained on the gusts met and within the accuracy of the sample, the answers obtained are the ones required. To obtain a proper understanding of aircraft in gusts it is necessary to supplement this work by special flight investigations, such as the thunderstorm project in America. In this paper only aircraft on normal operation duties will be discussed. The measurement of gusts will be concentrated on and such allied problems as fatigue and static design load requirements will be omitted.

2. Definition of a Gust

Before defining a gust it should be pointed out that it is not merely air in motion, whether upwards, downwards or horizontal. Fig. 1 shows one of Mr. Cody's kites being launched in 1907. A kite receives a load which is dependent on the absolute velocity of the air and it is possible to estimate the velocity of the air from a knowledge of the lifting characteristics of the kite, its weight and the conditions of the cable to which it is attached.

For aircraft the absolute value of air velocity in any direction does not appreciably influence the loads on the aircraft, for it is trimmed to fly steadily under the prevailing air conditions. However, changes of air velocity produce changes of load and such changes are known as gusts. This does not mean that when meeting a gust the absolute velocity of the air need be zero either at the beginning or at the end of the gust. Fig. 2 gives a diagrammatic representation of air velocity, aircraft velocity and aircraft normal acceleration. The upper curve shows the air vertical velocity with a number of discreet changes in velocity. The aircraft, however, is flown as far as practicable at a constant height and so the aircraft vertical velocity is maintained approximately zero, irrespective of whether the air is moving up or down. In both cases the average vertical velocity over a long period will be zero, but an attempt is made in the control of the aircraft to reduce the vertical velocity to zero whenever the air tends to deflect it. The aircraft normal acceleration is shown in the lower curve. Here there is a greater tendency to maintain a constant mean value, which is $1g$.

In comparing these three curves it can be seen that although they all have a mean value such that there is no movement up or down, the air may depart from zero velocity for long periods, the aircraft velocity for not such long periods and the accelerations for the shortest periods. On this diagram is shown a typical gust, where it can be seen that the absolute value of the air velocity was up before, and down after, the gust. It so happens that the aircraft vertical velocity had not completely returned to its near value after the previous gust, but the normal acceleration had.

A gust may be defined as a rapid change of velocity relative to an aircraft moving along its normal flight

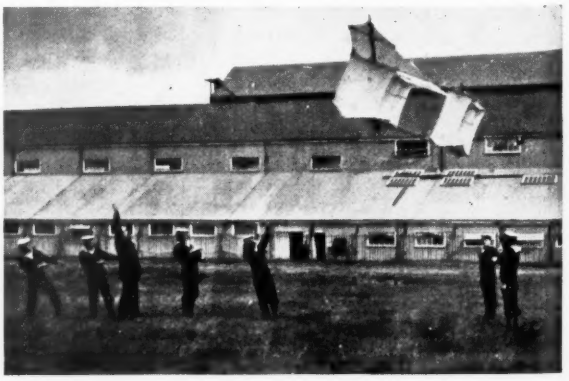

FIGURE 1. Mr. S. F. Cody instructing sailors in kite flying, 1907.

*Based on a Section Lecture given to the Society in November 1953.

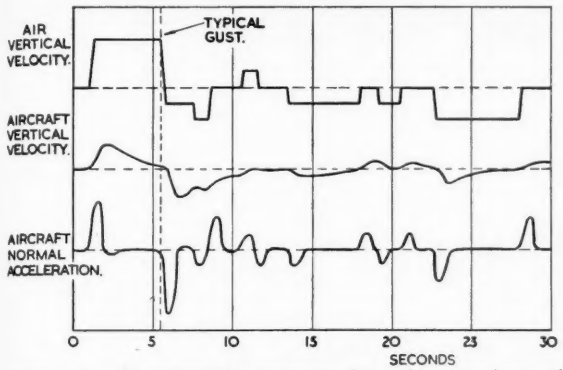

FIGURE 2. Diagrammatic representation of comparison of aircraft normal acceleration with aircraft and air vertical velocities.

path. There can be combinations of changes, but in the author's opinion these are regarded as multiple gusts. In any case, if multiple gusts are considered there would be no limit to such concepts. With this simple definition of a gust there is still not a unique connection between a gust and the acceleration at the aircraft centre of gravity.

In Fig. 3 three different gusts are compared. It is accepted that there is always a linear gradient to the gust. This is no great handicap, as the difference between linear gradient and other shapes, such as a cosine shape, is very small. On the left is a sharp edge gust, the second curve is one with a gradient extending over five chord lengths and the third, one extending over ten chord lengths. In each case the acceleration peak has the same magnitude, but the velocity of the gust is different. As can be seen the velocities are $U/0{\cdot}76$, $U/0{\cdot}69$ and $U/0{\cdot}60$ respectively for the three different gradients. The scale for the acceleration will be discussed later.

For the purpose of deducing loads on aircraft it is convenient to have a unique relationship between the acceleration at the centre of gravity and the gust velocity. It is convenient, therefore, to think of the three gusts shown here as being identical and to select one as a standard equivalent gust. Then the formula relating this standard equivalent gust with acceleration is used to give a unique value for gust velocity corresponding to a particular acceleration. These gusts are grouped and subsequently changed back into accelerations using the same formula as before. No first order error can occur in the deduction of such acceleration if only one aircraft is used in the experiment for we start with the accelerations, use gust velocity as an intermediary and then return again to the identical accelerations that we started with. But such information is always used to extrapolate from one aircraft to another and then the accuracy of the deductions depends on the similarity of the two aircraft with regard to the formula used.

3. Gust Formulae

The first stage in the early examination of gusts was to consider a simple sharp edge gust. Such a formula, which is the same as the one shown in Fig. 4 with K = unity, is deduced on the following assumptions.

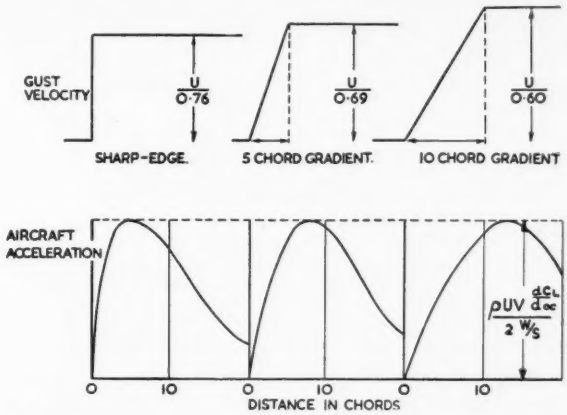

FIGURE 3. Comparison of gusts producing same peak acceleration. Aircraft aspect ratio of 6 and mass parameter 10. Shape of acceleration curves only approximate.

First, there should be an instantaneous change of gust velocity, which is uniform across the span of the aircraft and perpendicular to it. Second, the aircraft's flight path is completely unaffected by the gust, *i.e.* there is no vertical velocity, nor is there pitch. Third, the tail loads are neglected and fourth, the lift is proportional to the incidence of the wing and independent of time. Kussner modified this formula by including a linear change in gust velocity up to its maximum value. He

GUST FORMULA

$$\Delta n = K \frac{\rho U V \frac{dC_L}{d\alpha}}{2\frac{W}{S}}$$

where K = gust alleviation factor

K is determined as the maximum value of the force function $\Lambda(s)$, which is given by

$$\Lambda(s) + \frac{1}{\mu_g}\int_0^s \Phi(s-\sigma)\,.\,\Lambda(\sigma)\,.\,d\sigma - \Psi(s) = 0$$

Notation

Δn = acceleration increment
ρ = air density
W = aircraft weight
S = wing area
s = distance

μ_g = mass parameter $= \dfrac{2W}{\rho g\, Sc}\,\dfrac{dC_L}{d\alpha}$

Φ = unsteady lift function due to sudden change of incidence
Ψ = unsteady lift function due to penetration into sharp-edge gust

$\Lambda = \dfrac{\mu_g}{U}\cdot\dfrac{dw}{ds}$

U = gust velocity
V = aircraft forward velocity
$\dfrac{dC_L}{d\alpha}$ = lift slope
c = wing mean chord
w = aircraft vertical velocity

FIGURE 4. Gust formula.

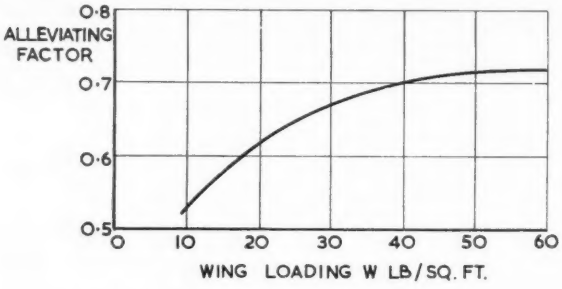

FIGURE 5. Alleviating factor for vertical gusts.

also allowed for vertical motion, but not pitching of the aircraft or tail loads. In addition, he used the Kussner and Wagner unsteady lift functions for infinite wings. This basic method for determining gusts is shown in Fig. 4. The first equation gives the acceleration in terms of various properties of the aircraft and the air speed. The alleviation factor is determined as the maximum value of the force function which is given by the second equation. Zbrozek extended Kussner's work by solving this equation for different aspect ratios and has computed the solutions for larger mass parameters.

For practically all work on gusts that has been done up to the present time, a much simplified alleviation factor related to wing loading instead of mass parameter has been used in both America and England. Fortunately the two countries have an identical rate of change in alleviation factor with wing loading, the American one being 10/6 times that of the English for all wing loadings. The English alleviation factor is shown in Fig. 5 and is taken from A.P.970. As long as the wing loading is more or less proportional to the mass parameter, it does not matter that the alleviation factor is not exact in giving the absolute value of the change of air velocity. The present paper uses throughout the alleviation factors as shown in this figure. No great difficulty, other than that of computation, would be experienced if it were decided to change over to the more rigorous alleviation factor based on mass parameter, as the original accelerations are still available.

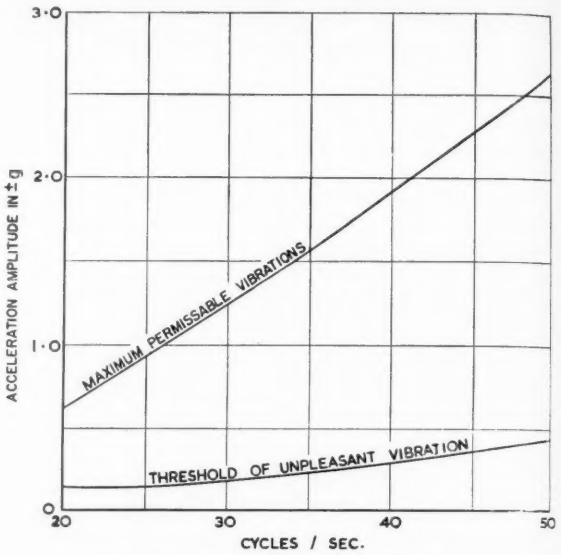

FIGURE 7. Accelerations due to vibration.

This will almost certainly be done in the near future, but for a time it will be necessary to do all gust work using both alleviation factors, in order to compare present results with the requirements which are given in A.P.970.

4. Relationship of Accelerometer Loadings to the Acceleration of the Aircraft Centre of Gravity

So far all the comparisons have been between acceleration of the aircraft centre of gravity and the gust velocity. In practice it is not possible to measure acceleration at the aircraft centre of gravity, as all aircraft are flexible and therefore the centre of gravity moves relative to the aircraft structure. When a flexible aircraft meets a gust it will experience accelerations and strains due to the gust load and, in addition, certain dynamic effects due to the flexibility of the structure

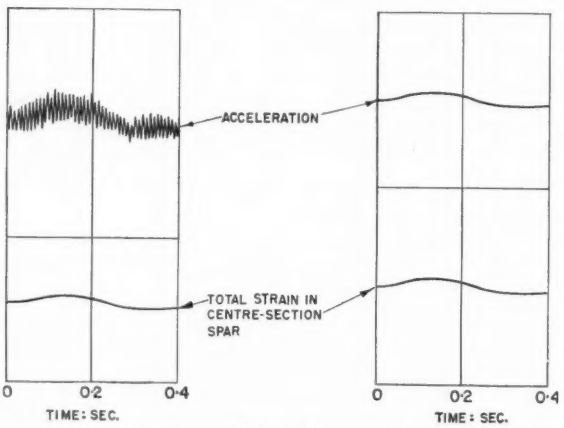

FIGURE 6.

Combined gust and vibration acceleration and strain.

Gust acceleration and strain with vibration acceleration removed.

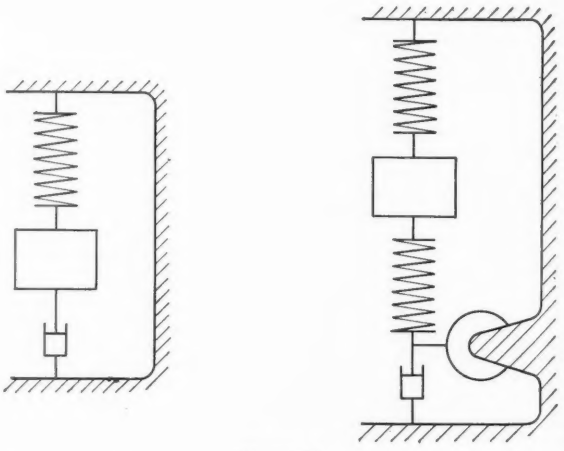

FIGURE 8.

Simple accelerometer.

Compound accelerometer.

itself. In predicting the gust load it is necessary to make some correction for these dynamic effects.

For operational use it is not practicable to have more than one accelerometer to an aircraft. This is placed near the aircraft centre of gravity when the aircraft is stationary. There will be an over-shoot to this accelerometer due to flexibility. In the present calculations the actual readings on the accelerometer have been used and thus there is a hidden dynamic over-shoot on acceleration. If in the future it is decided to do more elaborate calculations it will be necessary to correct for this over-shoot.

From the structural standpoint strain is the more important phenomenon; it has been found on a number of aircraft that on average the over-shoot of the individual accelerometer is much the same as the over-shoot of strain over the whole wings.

5. Requirements for Accelerometer

Figure 6 gives the acceleration measured near an aircraft centre of gravity and compares it with the total strain in the centre section spar. It can be seen that there is a high frequency acceleration superimposed on a low frequency acceleration similar in shape to the low frequency change in strain. This high frequency acceleration is due to vibrations in the aircraft structure and, as can be seen, the correlation of acceleration and strain is quite different from the correlation of acceleration and strain in a gust. To measure the acceleration due to gusts, it is essential to reject this high frequency acceleration. Fig. 7 gives the accelerations due to vibration in aircraft. It can be seen that the maximum permissible vibration at 40 cycles per second is about $\pm 2g$. As the interest lies in measuring accelerations of the order of 1/10th g to reasonable accuracy, the filtering of the high frequency vibration must be extremely good. When a record of acceleration against time is made it is possible, although inconvenient, to do some of the filtering by inspection of the record. When counting is done automatically on the instrument, such inspection is not possible and a greater amount of filtering must be done by the accelerometer itself.

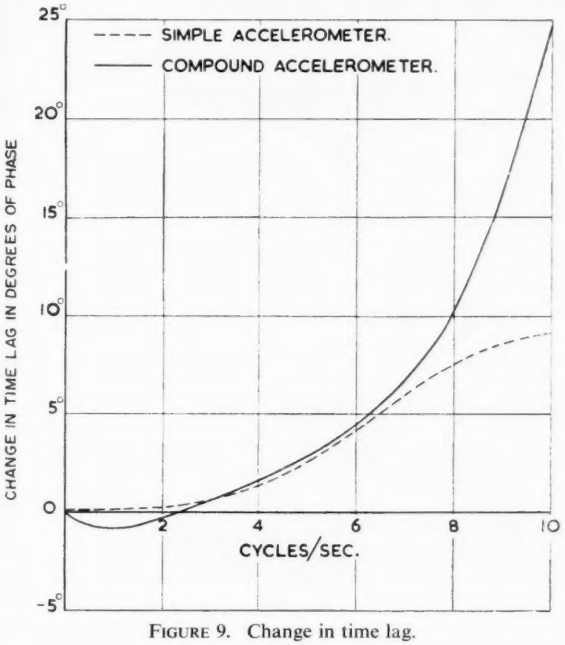

FIGURE 9. Change in time lag.

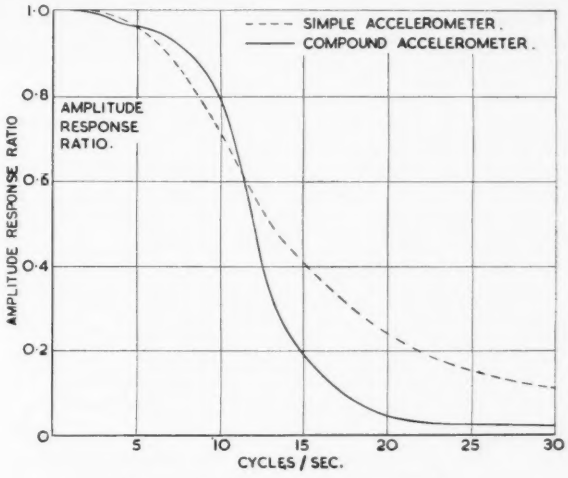

FIGURE 10. Amplitude response ratio.

A simple accelerometer and a compound accelerometer are shown in Fig. 8. The one on the left is an ordinary simple accelerometer, consisting of a spring, a mass and a damper unit between the mass and the case of the instrument. With such an instrument the damping is chosen to give good response at low frequency. When this is done the response at high frequency is practically fixed. The addition of a second spring and rotary inertia, as shown in the figure on the right, increases the filtering of the high frequency. The damping is again chosen so that satisfactory low frequency response is achieved and the ratios of the secondary spring and inertia are chosen to give the lowest high frequency response compatible with not spoiling the low frequency response.

The next figures give the response of the two types of accelerometer. There are two ways in which an accelerometer can give faulty information. One is that the information is distorted due to the time lag in recording the information being different for different frequencies. (Clearly, there is no distortion if time lag

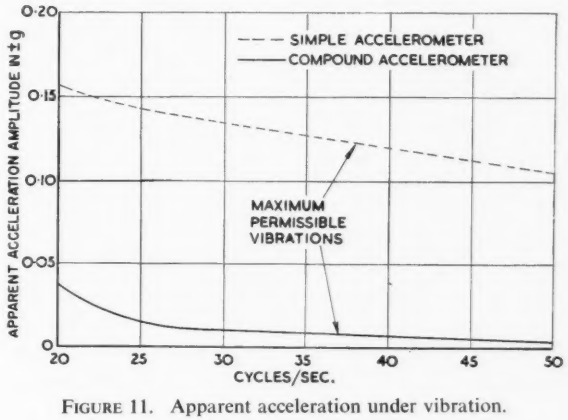

FIGURE 11. Apparent acceleration under vibration.

is constant, whether it be a fraction of a second or several days and therefore difference is the only thing that matters). The other is the ratio of recorded to actual acceleration may differ from unity. Fig. 9 shows the change in time lag of the accelerometers, in terms of degrees of phase, under sinusoidal motion of different frequencies. It can be seen that this is completely satisfactory up to 6 cycles per second, where the change is less than 5 degrees. Between 6 and 10 cycles per second the time lag increases appreciably, but the amount of information received in this range is a small proportion of the whole and the distortion will be small. Above 10 cycles per second, which is the limit of the instrument, it does not matter what the time lag is.

Figure 10 compares the amplitude response of the two instruments, again under a sinusoidal motion. Up to 6 cycles per second the response is more than 95 per cent. in both cases. Between 6 and 10 cycles the response drops to about 70-80 per cent. and this is quite adequate. Above 10 cycles per second, response of the compound accelerometer drops much faster than that of the simple accelerometer and so will be better able to reject the high frequency accelerations. This high frequency response is shown again in Fig. 11, where it can be seen that at 30 cycles per second even for the maximum permissible

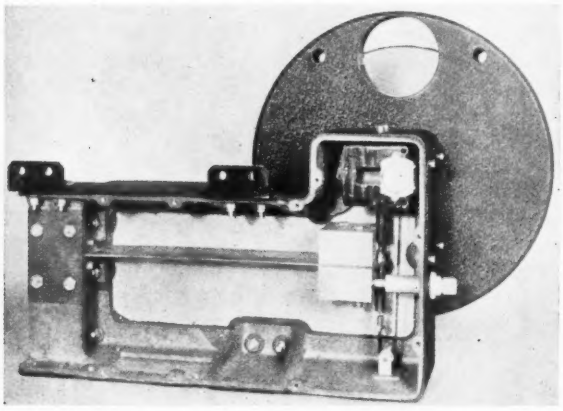

FIGURE 13. Counting accelerometer. Back view.

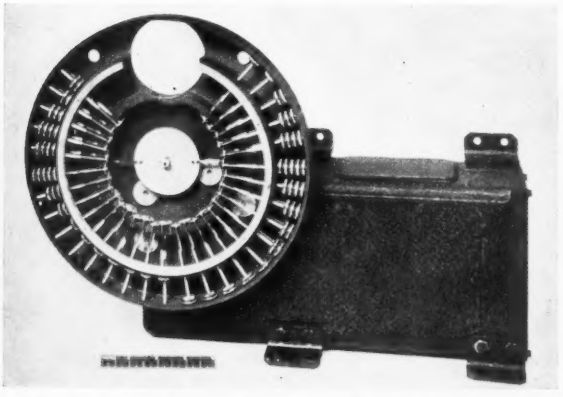

FIGURE 14. Counting accelerometer. Front view with front face removed.

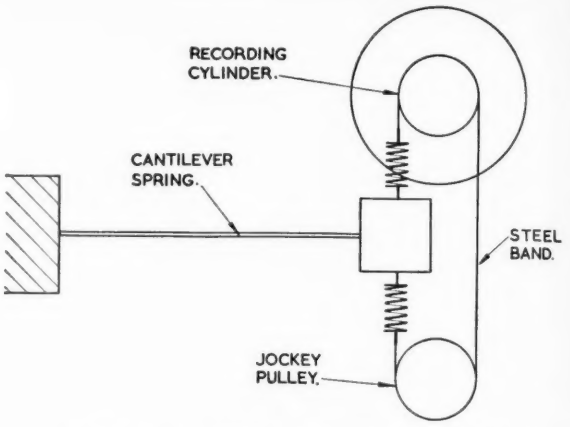

FIGURE 12. Diagrammatic representation of actual accelerometer.

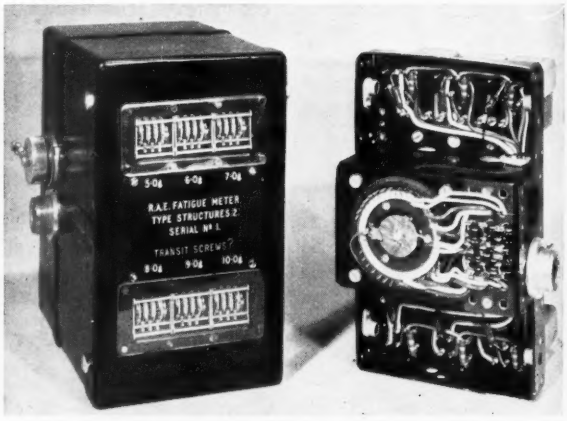

FIGURE 15. R.A.E. fatigue meter.

FIGURE 16. A *V-g* recorder.

vibrations the compound accelerometer has an apparent acceleration amplitude of 1/100th g, the simple accelerometer being rather more than ten times this value.

6. Accelerometers

Figure 12 gives a diagrammatic representation of a counting accelerometer which uses a compound accelerometer. The first mass and spring consist of a cantilever spring with a weight on the end. The secondary spring is in the form of two spiral springs connected through an endless steel band over two pulleys. These springs are pre-tensioned so that they will respond to compression as well as tension loads. The recording cylinder at the top also includes the damper unit. Figs. 13 and 14 give the actual counting accelerometer as used. Fig. 13 is a back view of the accelerometer where the cantilever spring and mass are clearly visible; the secondary springs and endless band can just be seen to the right hand side of the mass. Eddy currents damping is used in the damping unit which is situated just above the mass. The eddy currents are generated in an aluminium cylinder as it rotates between the poles of a permanent magnet. In order to develop sufficient damping, a gearing of 9 to 1 between the top roller and the aluminium cylinder is necessary.

Figure 14 is a front view of the accelerometer. The spindle on which the aluminium cylinder is attached passes through the case and on the front is attached the rotary inertia. This rotary inertia is also used as part of the pointer for operating the counters. A small ratchet is connected through a torsion spring to each counter. When an acceleration is imposed on the instrument, the pointer moves with little resistance over the ratchets to a position corresponding to the acceleration. On returning to its datum it picks up one tooth of each ratchet that it has crossed and moves the counter on one step. The rotary inertia can only have 180° of travel and for convenience in spacing the counters, two pointers are used.

This instrument has been in use for about four years and it has been found that to obtain a gust spectrum it is not necessary to count at the thirty levels used in the first instrument. With as many as thirty counting levels it had been found that the weight of thirty electrical counting systems, excluding the accelerometer, was greater than the complete mechanical accelerometer. By reducing the number of counting levels to six, electrical counting becomes attractive provided that a smaller accelerometer could be designed for electrical counting. Such an accelerometer having the same principles of operation as the original, has been designed. The complete instrument is known as a fatigue meter and is shown in Fig. 15. It is 6 in. high and weighs 4 lb. compared with 12 lb. for the original counting accelerometer. This paper is mainly concerned with accelerations measured with the counting accelerometer, but Fig. 16 shows a picture of the V-g recorder. This N.A.C.A. instrument was designed for the measurement of the infrequent high accelerations and associated velocity and is therefore a suitable type of instrument for measuring high gusts.

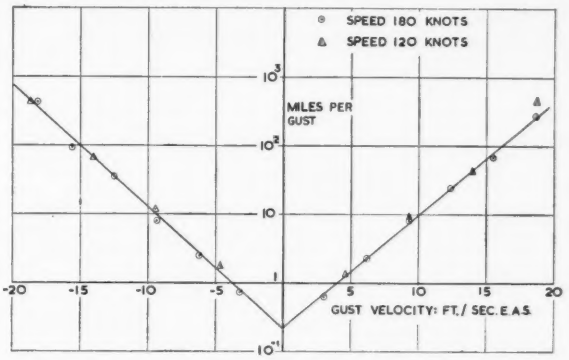

FIGURE 17. Gusts met by Viking at two speeds.

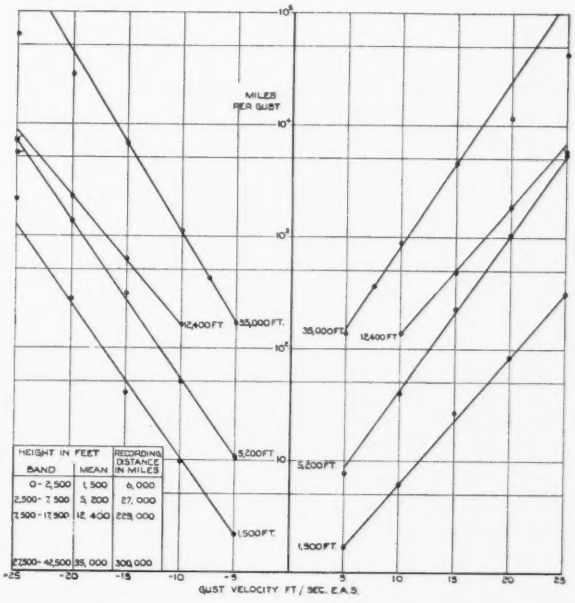

FIGURE 18. Gust spectrum at different height bands in terms of miles per gust of given magnitude or greater.

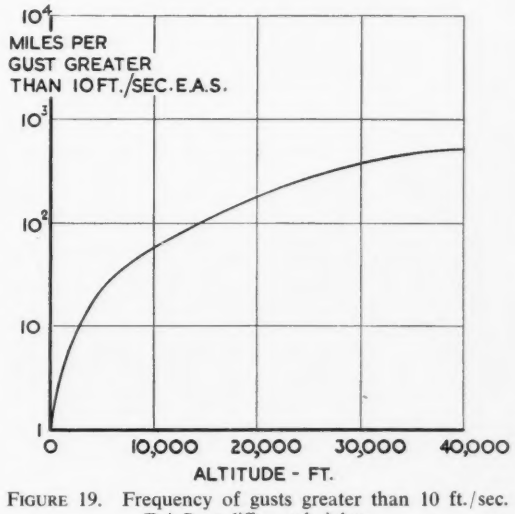

FIGURE 19. Frequency of gusts greater than 10 ft./sec. E.A.S. at different heights.

7. Results

In order to use the counting accelerometer to predict a gust spectrum it is necessary to know the height and speed of the aircraft when the counts are made. To do this an automatic observer is added to the accelerometer and photographs are taken at 10 minute intervals of the height and speed of the aircraft, in addition to the acceleration counts. The complete installation weighs about 30 lb. and the information obtained from it requires considerable analysis.

Before giving the results obtained with this instrument, it is necessary to decide whether gusts should be recorded in distance or in time. It was thought that distance would be the better method and to establish that this was so, a short experiment was done with a Viking flying at two different speeds. To eliminate atmospheric variations the experiment was conducted by having the aircraft fly first for four minutes at 120 knots and then, after one minute, to change speed and fly for four minutes at 180 knots; this was repeated ten times in one flight. The results shown in Fig. 17 are for ten such flights, which make a total of one hundred readings at 120 knots and one hundred readings at 180 knots. Good agreement is obtained in terms of miles per gust of given magnitude.

Figure 18 gives the gust spectrum at different height bands in terms of miles per gust of given magnitude or greater. It can be seen that there are records for over 200,000 miles at an average height of 12,400 ft. Most of this information was obtained on a Hermes. The 300,000 miles at an average of 35,000 ft. was obtained on a Comet. Another point to be noticed is that the amount of recording below 2,500 ft. is very small, being for only 6,000 miles and even at the next band, with an average of 5,000 ft., there are only records for 27,000 miles. The curve is deliberately cut off at 25 ft. per sec. equivalent air speed (E.A.S.) as the number of readings above that are insufficient to give a reliable estimate of the frequency of occurrence. It can be seen that up to this level the change in frequency is approximately logarithmic, with a slight tendency towards meeting more gusts of high magnitude than would be expected. The up and down gusts occur in approximately equal numbers. Fig. 19 is a re-plot of Fig. 18, to show the change of frequency of gusts with altitude. A 10 ft. per sec. equivalent air speed (E.A.S.) gust was chosen to illustrate this change.

With regard to the future, we have for some time been wondering whether there are differences in turbulence in different parts of the world. So far it has not been possible to detect any statistically significant differences in terms of height above land or water, but strenuous efforts are being made to determine whether there are any differences, particularly between land and sea and between tropics and temperate zones.

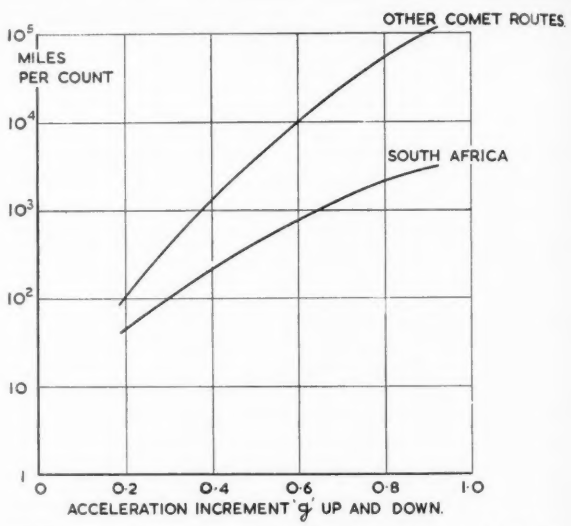

FIGURE 20. Comparison of Comet flying above 27,500 ft. on South African and other routes. Records in terms of acceleration of given magnitude or greater.

Figure 20 gives some tentative views of Mr. Heath-Smith, who did much of the analysis for the two previous figures, and who has been attempting to find geographical difference in turbulence. Fig. 20 shows the first difference that he has found that might become significant when further records become available. He has compared the acceleration counts on the Comet at high altitude and it can be seen that for the South Africa routes there are a far greater number of counts than for the other routes, particularly for the high gusts. The two curves have frequency differences of about three times for the lower gusts, increasing to thirty times for the higher ones.

ACKNOWLEDGMENT

The author wishes to thank the Chief Scientist, Ministry of Supply, for permission to give this paper, the illustrations of which are Crown Copyright reserved. The views expressed are his own and do not necessarily represent the views of his Department.

HENRY PHILLIP FOLLAND

O.B.E., F.R.Ae.S., F.I.Ae.S., F.R.S.A. 1889-1954

A TRIBUTE

WITH THE PASSING of Harry Folland, British aviation has lost one of its most distinguished designers of fighter aircraft during the formative period between the two world wars.

Henry Phillip Folland was born at Cambridge on 22nd January 1889 and, like many other boys of his time, he became intensely interested in motor cars. He went to Coventry and served an apprenticeship at the Lanchester Motor Company and stayed on in the town afterwards. I first knew him when he was on the drawing board at the Daimler Company.

While in Coventry, he became interested in aircraft and model aeroplanes, and eventually in 1912 he, together with several other engineers from the Daimler Company, was attracted down to Farnborough to the Royal Aircraft Factory, the new Government department which had recently been set-up, under the leadership of Colonel O'Gorman, on the site of the old balloon factory near Laffans Plain. There is no doubt that history has shown that this was a unique place, and you can hardly turn anywhere in British aviation without finding that the good things that were done on aircraft between the two wars stem almost entirely from engineers who had been at this remarkable place, and who were inspired by an outstanding leader.

While there, Folland was associated with F. M. Green, the Chief Engineer, who also came from Daimlers, and he became a section leader in the Design Office on single-seater fighters, developing the S.E.4 and later the S.E.5, which went into production and was the most advanced British single-seater fighter at the end of the 1914-18 War. In 1917 there occurred the astounding Public Enquiry, in the middle of a major war, into the Royal Aircraft Factory, which was, in fact, the first murmuring against a nationalised industry. At the time, the disbanding of the technical staff as a result of this enquiry looked like being a major disaster, but it turned out to be a blessing as people like Folland, who had had a splendid grounding on all matters of aeronautical design, had to go out into industry and find a job for themselves.

Folland joined the Nieuport Company at Cricklewood with two other Farnborough people, Heckstall-Smith and Hall (later Chief Engineer of Imperial Airways), and designed two or three successful types of machine towards the end of the war. He produced the Nieuport "Nighthawk" fighter and was in the course of designing an interesting plywood, tri-plane, twin-engined bomber when peace was proclaimed and the Nieuport Company, a financial venture of the Waring Group, which had been started for aircraft subcontracting work during the war, was wound up and Folland and his associates again found themselves looking for a job.

This time he was more fortunate, and he took his small team to the Gloucestershire Aircraft Company, an off-shoot of H. H. Martin, the famous Cheltenham architectural specialists. Their aviation subsidiary was

formed during the war to manufacture D.H.4 wings and other components, but they decided after the war to try to remain in the aircraft business.

H. E. Preston, his faithful henchman, who had followed him from Farnborough to Cricklewood, came also and remained Folland's chief technical man without a break for 35 years; the Gibson brothers, still in the Gloster design office today, were also among the small band who put their faith in Folland.

The new Gloucestershire design team's first success was the Gloster I Bamel racer, with a Napier engine, which won the Aerial Derby, and several other events.

From the production point of view, there followed four successful biplane fighters, the Grebe, which was a productionised version of the Nighthawk, the Gamecock, the Gauntlet, and the Gladiator. All these machines went into considerable production for the Royal Air Force, and built up an enviable reputation, the Gladiator doing yeoman service in the early days of the Second World War. It was the first British machine to destroy an enemy aircraft. Three of them put up a wonderful show in the defence of Malta, while a handful did well in the abortive invasion of Norway, operating from a frozen lake. All this series of fighters was immediately recognised in the air by the Folland hall-mark, and in this family of air-cooled, radial, single-seater fighters Folland and his team specialised on neat and painstaking detail design, weight-saving, harmonised controls, and gradual refinement of form.

Following on the Bamel success, Folland undertook a series of racing machines, the Gloster III, IV and VI. The Gloster III was a British challenger at Baltimore, U.S.A. The Gloster IV was, I think, the finest biplane design that was ever produced. It was flown in the

Schneider Trophy race in 1927 at Venice by Kincaid, and did the fastest lap, but unfortunately had an engine failure and a forced landing, and did not finish the race.

The Gloster VI, a monoplane which was built for the final Schneider Trophy race of 1931, was also a very attractive and finished design. It did a remarkable speed, but was out of the picture because other competing machines had more than 50 per cent. more power.

Folland and his design team put a tremendous amount of effort into this series of Schneider Trophy racers and the machines were superbly finished. It was unfortunate that they were not afforded a better opportunity for success.

In 1929, the company changed its name to the Gloster Aircraft Company and moved from its original works in Cheltenham, adjoining Lansdown Station, to Brockworth Aerodrome, Folland becoming Chief Engineer.

During the next few years, he developed a number of new and promising prototypes, including a single-seater monoplane fighter and a twin-engine fighter, and also took a deep interest in the Heleshaw variable-pitch propeller.

In the early 'thirties, I think Folland became somewhat frustrated and worried about his future, and I remember so well dining with him at Maidenhead on the way home from a Royal Air Force Pageant, and his unfolding to me his dreams for the future and the great urge he had to set up his own company. This dream eventually came true in 1937, and he took over the fine buildings at Hamble, near Southampton, of the defunct British Marine Company. He moved there in the autumn of that year with the same nucleus team, and he set to work with tremendous energy and enthusiasm to build up an organisation.

His natural desire and flair was to create a new design of aircraft and he put in several, but the only order for his own design he received from the Air Ministry was for a small batch of high-altitude Test Bed machines. This I do not think was Folland's fault, as by this time the re-armament drive for the R.A.F. was in full swing and new types had been selected and frozen for production.

Undoubtedly it showed the character of the man that he was able, with his good engineering sense and technical background, to throw himself whole heartedly into the works side, and to take on a number of sub-contracts such as for Blenheim and Spitfire, so that by the time the war broke out he had built up a really good production set-up. No doubt he benefited by his racing experience in taking this balanced and sensible line, because I know he always felt that his Schneider Trophy effort, extremely good though it was, had detracted from his day-to-day current "bread and butter" production work. In 1942 he did produce a most promising air-cooled fighter in the true Folland tradition, but the design team responsible for it was taken from him by the powers-that-be of that time, which I know he felt very much indeed.

Throughout the war, however, Folland put in a prodigious amount of work and built up an enviable reputation for sound engineering and production technique. His total force rose to over 3,000 work people, and he took on a big range of work, including complete Spitfire wings, Wellington nacelles, and so on.

At the cessation of hostilities, he laid his works plans carefully for the future and was able to keep his factory going on a number of post-war subcontracts. He also had a small design team running under Preston, which made some project investigations into both military and civil types, but I felt his great enthusiasm and drive on design had gone.

I saw quite a bit of Folland during this period, and I always thought his great effort during the war had overtaxed his strength. The many responsibilities of building up an organisation of this kind in such a short time, and without many senior people round him, had told upon him, and in 1951 he had to step down, which he did with dignity and grace, and was fortunate to have W. E. W. Petter to succeed him.

Folland was a very human and kind man. No one could come into close touch with him without appreciating these qualities. He was always approachable, and there are many who have had a helping hand from him. He was capable of rising to great heights if he was given the opportunity and inspiration. He, in his turn, had the great gift of leadership, and he inspired loyalty and friendship among his colleagues and staff.

An early football accident to his ankle caused him difficulty all through his life. This did not prevent him from taking an interest in games and sport, and playing a reasonable game of golf and bowls. Of recent years he was generally to be seen at the Cheltenham Cricket week with the inevitable pipe and a rose in his buttonhole, having become a keen gardener.

His wife and two sons—both in the Aircraft Industry—survive him. He and Mrs. Folland were actually with their youngest son at Nottingham, when he passed away last September.

He was made a Fellow of the Royal Aeronautical Society in 1920, and took an interest in the local Gloucester and Cheltenham Branch of the Society.

In accordance with his will, his ashes were recently scattered by an R.A.F. pilot over Laffans Plain, the scene of his early triumphs.

Thus has passed, at the age of 65, one of our most distinguished British aircraft designers between the two wars. A man who had the capacity of imparting great enthusiasm to his staff and inspiring attention to detail and good design. His first love was undoubtedly the single-seater land fighter. He had not the time to give a great deal of attention to larger machines or civil aircraft, but his twin-engine survey machine, however, which really could fly long distances on one engine, did much valuable work.

It is a great satisfaction to his many old friends that towards the end of his life he was afforded the opportunity to realise his dream and build up his own firm and make a success of it, although not from a design point of view, but from the manufacturing and production angles. It is believed that the Folland hall-mark has gone into the Hamble factory and a tradition built up which may well lead on to great things for the future.—ROY FEDDEN.

TECHNICAL NOTES

Contributions to this Section of the JOURNAL *will be eligible for Journal Premium Awards and will normally be published within two months of being received.*

The Design of Static and Pitot Static Tubes for Subsonic Speeds

by
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THE DESIGN of the static and pitot static tubes which are still in common use—such as the National Physical Laboratory standard head or the Prandtl tube, dates back some forty years (*see* Ref. 1). Before these tubes can be used it is necessary to calibrate them, using a replica of the instrument which is commonly regarded as the standard. This procedure assumes a perfect replica. Furthermore, the shape of the instrument head used hitherto (conical or hemispherical) is known to be aerodynamically poor and, as a consequence, the calibration factor varies unpredictably with wind speed, stream turbulence and Mach number. The original calibration of the N.P.L. standard head, which applied only to wind speeds of the order of 60 ft./sec., is now shown to be inaccurate. For instance, it was found by the author that the static pressure reading of the instrument was in error by about one per cent. of the dynamic head at the relatively low wind speed of 200 ft./sec. The need was felt therefore for a new instrument designed on a rational basis.

1. DESIGN OF STATIC TUBE

It was considered that the new design should fulfil the following conditions:—

(*i*) The shape of the head of the instrument should be given by a simple geometric relationship so that it can be reproduced with high accuracy; it should also be such that it cannot easily be damaged.

(*ii*) The shape of the head should be designed to avoid pronounced suction peaks, flow separation and premature shock waves. The reading of static pressure would then be independent of Reynolds number. For high subsonic speeds the correction due to compressibility may be calculated.

(*iii*) It should be possible to calculate the correction to static pressure reading for any fineness ratio of the head or position of static slot or hole.

(*iv*) The supporting strut should be so shaped that flow separation, which is usually unavoidable, is always in the same position. The correction to static pressure reading due to the pressure field ahead of the strut can then be estimated for any size or configuration and it will be independent of wind speed.

Two head shapes were considered. The first was a body produced from a single source and the second a semi-ellipsoid faired into a cylindrical tube. From the calculated pressure distributions for the two shapes it was decided to use the semi-ellipsoidal head with a static slot six tube diameters aft of the nose. The choice was determined by the fact that, although at this position the calculated error of the semi-ellipsoidal head ($\Delta C_{PH} = -0{\cdot}0054$) is rather more than that for the "single source" head ($\Delta C_{PH} = -0{\cdot}0038$), the former has lower values of peak suction forward of the slot, which should react more favourably on the boundary layer. Consequently, the elliptical head should be less sensitive than the "single source" head to changes of pressure distribution occurring at high Mach numbers.

The shape of the head is given by equations (1) and (2) as follows:

$$\frac{r}{R} = \sqrt{\left\{ \frac{2\left(\frac{x}{R}\right)}{a} - \left(\frac{x/R}{a}\right)^2 \right\}} \quad \text{for} \quad 0 \leqslant \frac{x}{R} \leqslant a \qquad (1)$$

$$\frac{r}{R} = 1 \quad \text{for} \quad \frac{x}{R} \geqslant a \qquad (2)$$

where the semi-axes of the semi-ellipsoid of revolution are aR, R, R faired into a cylindrical tube of radius R at a distance a, in terms of the maximum tube radius R, aft of the nose. r is the radius of the tube at a point x from the nose.

The pressure coefficients at the surface are given by

$$C_p = 1 - \left[1 + \frac{v_x}{V_0}\right]^2 - \left[\frac{v_r}{V_0}\right]^2 \qquad (3)$$

where

$$\frac{v_x}{V_0} = -\frac{1}{2a\sqrt{\left\{\left(\frac{x}{R}\right)^2 + \left(\frac{r}{R}\right)^2\right\}}} + \frac{1}{2a^2}\log_e\left(\frac{a - \left(\frac{x}{R}\right) + \sqrt{\left\{\left(a - \frac{x}{R}\right)^2 + \left(\frac{r}{R}\right)^2\right\}}}{-\left(\frac{x}{R}\right) + \sqrt{\left\{\left(\frac{x}{R}\right)^2 + \left(\frac{r}{R}\right)^2\right\}}}\right) \qquad (4)$$

and

$$\frac{v_r}{V_0} = -\frac{1}{2\pi^2\left(\frac{r}{R}\right)}\left\{\sqrt{\left\{\left(a - \frac{x}{R}\right)^2 + \left(\frac{r}{R}\right)^2\right\}} - \sqrt{\left\{\left(\frac{x}{R}\right)^2 + \left(\frac{r}{R}\right)^2\right\}} + \frac{a\frac{x}{R}}{\sqrt{\left\{\left(\frac{x}{R}\right)^2 + \left(\frac{r}{R}\right)^2\right\}}}\right\} \qquad (5)$$

Received September 1954.

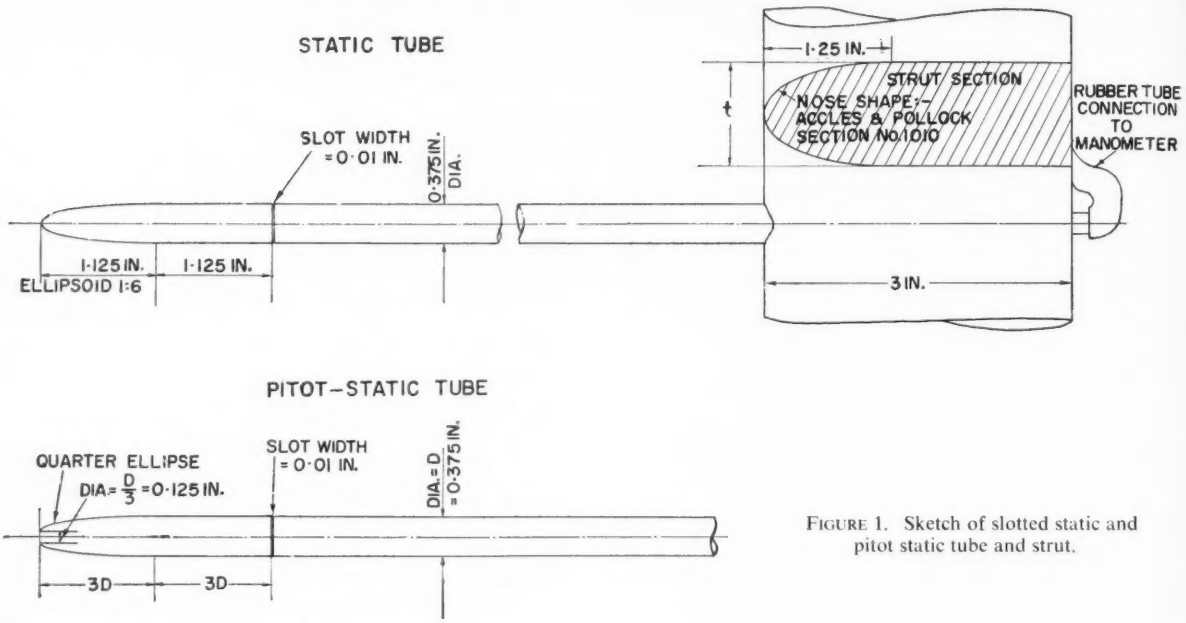

FIGURE 1. Sketch of slotted static and pitot static tube and strut.

are the velocity increments in the x and r directions. With $a=6$, this gives $\Delta C_{PH}=-0{\cdot}0054$, the corrections to the static pressure reading due to the nose shape of the tube in terms of the dynamic head. Corrections to allow for the effect of compressibility (in the absence of shock waves) may be made by means of the following simple rule (*see* Ref. 2) which is applicable to ellipsoids of revolution only.

$$\frac{C_P}{C_{Pi}}=\frac{1}{\sqrt[4]{(1-M_0^2)}} \quad . \quad . \quad . \quad (6)$$

The strut supporting the tube is designed to have a pressure field as far as possible independent of Reynolds number and turbulence, *i.e.* the conventional streamlined nose or semi-ellipse is faired into a short parallel-sided section; the rear surface is flat and normal to the side surfaces. The strut increases the static pressure at the slot relative to the tube pressure by an amount* which is given in Appendix III of Ref. 3 by

$$\Delta C_{P\,strut}=\frac{1}{\pi}\frac{t}{D}\frac{1}{l/D}\left(\frac{K_1+K_2 l/D}{K_1+l/D}\right) \quad . \quad (7)$$

where $\dfrac{l}{D}=\dfrac{\text{distance of slot ahead of strut leading edge}}{\text{tube diameter}}$

t = strut thickness.

K_1 is a constant which depends on the fineness ratio of the strut and is shown later to have a value 10†.

K_2 is a constant which is shown in Ref. 4 to have a value 0·43.

($K_2=t_1/t$, the ratio between the displacement thickness far behind in the wake, and the thickness of the strut.)

Thus the total correction to the static pressure reading due to the nose shape and pressure field of the supporting strut is given by

$$\Delta C_P=\frac{0{\cdot}88}{l/D}\left(\frac{10+0{\cdot}43 l/D}{10+l/D}\right)-0{\cdot}0054. \quad . \quad (8)$$

Low speed wind tunnel tests were made on a static tube mounted at the mid-span of a strut (Fig. 1) for which the calculated value of ΔC_P is given by equation (8).

Figure 2 shows that the measured values of C_P agree well with the values calculated from equation (8) over the whole range of l/D tested. The tests showed that the value of ΔC_P did not vary with wind speed between 100 and 230 ft./sec. The effect of varying the width of the slot was also investigated. It was found that as the slot width was increased to 0·2 tube diameters the recorded pressure fell almost linearly, corresponding to a pressure drop of $0{\cdot}0113\times\frac{1}{2}\rho V_0^2$ per tube diameter. This is less than has been found for circular static holes[5] for which the pressure drop is about $0{\cdot}0263\times\frac{1}{2}\rho V_0^2$ per tube diameter. It was finally decided to adopt a slot width of 0·0267 diameters at which value the response to changes of static pressure is still reasonably rapid. The effect of rounding the outer edges of the slot is to increase the pressure reading by about $0{\cdot}0025\times\frac{1}{2}\rho V_0^2$ in the speed range 100 to 230 ft./sec. Care is needed in the manufacture of the tube and in keeping it clean. Otherwise, errors of the same order may be introduced.

The tests, which were made in two wind tunnels having different amounts of stream turbulence, showed that the readings of static pressure were affected by turbulence. Reference is made to this effect in *Wind Tunnel Technique* by Pankhurst and Holder[1] and further tests are needed to investigate this phenomenon.

2. DESIGN OF PITOT STATIC TUBE

The pitot static tube is designed as an air intake to have low suction peaks on the outside surface[6]. On this basis the ratio of the entry area of the tube to the maximum outside area of the tube (A_i/A_m) was chosen

*When the static tube is supported at the top of the strut, the value of $\Delta C_{p\,strut}$ is $\frac{1}{2}$ of that given in equation (7).

†$K_1=10$ is strictly true only for $l \gg t$.

to have a value of 1/9. The tube was mounted and tested in the same way as for the static tube. The exterior nose shape was elliptic, as shown in Fig. 1, over the front three diameters of the tube. The total head tube was expected to read true total head since

$$\frac{V_0 r}{\nu} \geqslant 7{,}000 \text{ (where } r = \text{radius of the mouth of the tube)}$$

which is well above the critical value of 30 required by the Barker criterion[1]. It is clear that the reading of static pressure on the pitot static tube will differ from that on the static tube only because of the nose shape. Hence, the constant, $-0{\cdot}0054$ in equation (8) is expected to have a different value. It is not possible to calculate the value of this correction but the tests showed that the variation of static pressure with distance from the strut is well approximated by

$$\Delta C_P = \frac{0{\cdot}88}{l/D}\left(\frac{10+0{\cdot}43l/D}{10+l/D}\right) - 0{\cdot}0038 \quad . \qquad (9)$$

the constant in equation (8) being replaced by $-0{\cdot}0038$. This constant is corrected to allow for compressibility by means of the factor $1/\sqrt{(1-M_0^2)}$. The static pressure reading was again shown to be independent of wind speed (100 – 230 ft./sec.). Readings of (total head static pressure) using the pitot static tube can be converted to $\frac{1}{2}\rho V^2$ by dividing by the factor

$$\left(1+\frac{1}{4}M_0^2+\frac{1}{40}M_0^4+\ldots\ldots\right) \quad (\textit{see} \text{ Ref. 7}).$$

ACKNOWLEDGMENT

The author acknowledges the permission of the Chief Scientist, Ministry of Supply, to publish this note, and wishes to thank Mrs. H. G. Alston, of the Ministry of Education, for her help in the experimental work and analysis of the results.

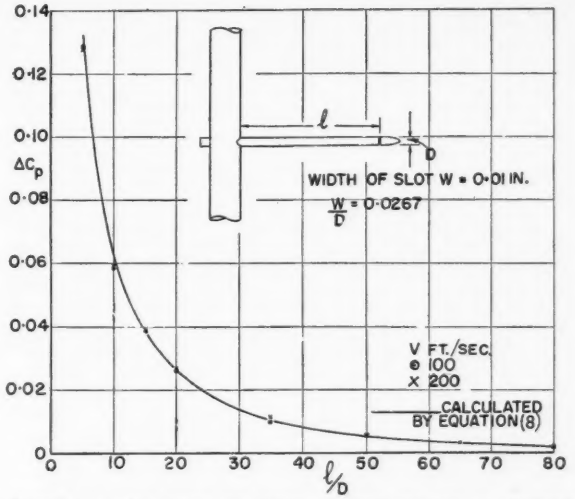

FIGURE 2. The effect on static pressure reading of distance from strut leading edge.

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Viscous Effects on Flattened Pitot Tubes at Low Speeds

by

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MEASUREMENTS were made of the pressures in flattened, blunt-nosed pitot tubes, in an air stream at Reynolds numbers from 13-1,000 (based on the external height of the tube). Three tubes were used, having cross sections with ratios of width to height (W/H) of 3, 7 and 11. The results are expressed in terms of a pressure coefficient $C_p = (P-p)/\frac{1}{2}\rho V^2$, where P is the pressure in the pitot tube, ρ is the density of the fluid, and p and V are the static pressure and velocity in the undisturbed stream. It was found that C_p decreased below 1 for all the tubes, although earlier measurements[1] had shown that this did not occur with circular tubes. The maximum decrease was about 1·6 per cent. at a Reynolds number of 65.

It was found that when the values of C_p for the tubes having ratios W/H of 7 and 11 were plotted against a Reynolds number based on *internal* height of the pitot-tube orifice, the curves were in good agreement. There is a general trend towards this limiting curve as the ratio W/H is increased from the value 1 (for a circular pitot tube).

Received 14th October 1954.

1. INTRODUCTION

Pitot tubes with flattened noses are often used for measuring velocity distribution in thin boundary layers, and if the velocity at the tube is small, the tube Reynolds number may be so low that viscous effects are important.

In a previous experiment to determine the viscous effect on the pressure in a *circular* blunt-nosed pitot tube[1], it was found that, at low speeds, the pressure in the pitot tube was greater than the true total pressure, and at no Reynolds number was the pitot-tube pressure

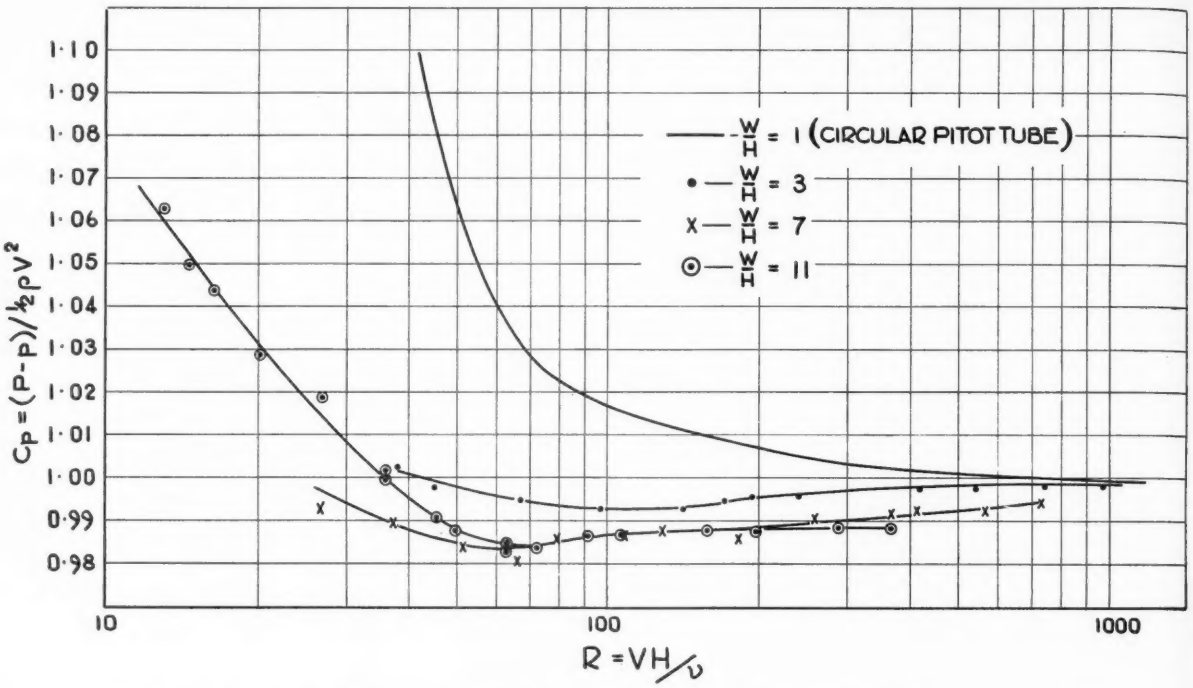

FIGURE 1. Pressure coefficient, plotted against Reynolds number based on external height of the pitot tube.

less than the true total pressure. It was also found that nose shape had an appreciable effect on pitot-tube pressure.

The experiments described here were made to investigate viscous effects on flattened pitot tubes.

The pressure in the pitot tube is expressed as a coefficient

$$C_p = \frac{P-p}{\frac{1}{2}\rho V^2}, \qquad . \quad . \quad (1)$$

where P is the pressure in the pitot tube, ρ is the density of the fluid, and p and V are the static pressure and velocity in the undisturbed stream. The Reynolds number is defined as

$$R = \frac{VH}{\nu}, \qquad . \quad . \quad . \quad (2)$$

where H is the external height of the pitot tube and ν is the kinematic viscosity of the fluid.

2. EXPERIMENTAL METHOD

The apparatus used was the same as in Ref. 1, each pitot tube being mounted on the centre line of a vertical pipe, near the entry. Assuming that the true total pressure ($p+\frac{1}{2}\rho V^2$) at the position of the pitot tube is equal to the atmospheric pressure P_a, equation (1) can be written as

$$C_p = \frac{P-p}{\frac{1}{2}\rho V^2} = 1 + \frac{P-P_a}{\frac{1}{2}\rho V^2}. \qquad . \quad (3)$$

The pressure difference ($P-P_a$) was measured with a sensitive, null-reading, inclined-tube manometer.

As stated in Ref. 1, the error in velocity due to the blocking effect of the largest circular pitot tube in the smallest pipe could not exceed 1½ per cent. Since the flattened pitot tubes were smaller than this largest circular one, it was decided to neglect this small error and determine the velocity directly from the measured difference between the atmospheric pressure and the static pressure at the hole in the wall, with the pitot tube in place. In this method of determining the velocity, any variation of static pressure across the pipe is neglected. It should be noted, however, that any errors from these causes affect only V in equation (3), and so cannot have any appreciable effect on C_p.

TABLE I

External width W	*External height H*	*Internal height h*	W/H	h/H
0·0418	0·0138	0·0111	3·04	0·805
0·0734	0·0104	0·0048	7·05	0·462
0·0557	0·0053	0·0018	10·51	0·340

The pitot tubes were made by flattening circular hypodermic tubing. Details of the tubes are given in Table 1.

3. RESULTS

In Fig. 1, C_p is plotted against Reynolds number based on external height (VH/ν). A mean curve showing the results of Ref. 1 for circular pitot tubes ($W/H=1$) is also included.

The curves of Fig. 1 do not show clearly an approach to a limiting curve for large W/H. This may perhaps be because the ratio of internal to external height (h/H) was not kept constant.

In Fig. 2 the results are replotted, using as abscissa the Reynolds number $R'=Vh/\nu$, where h is the internal height of the pitot tube orifice. The curves for $W/H=7$

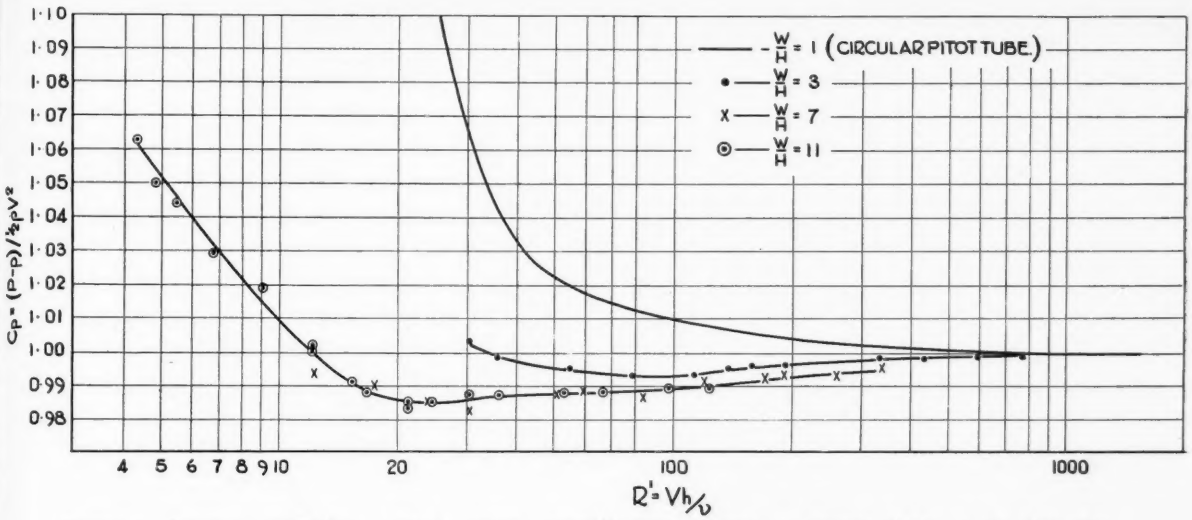

FIGURE 2. Pressure coefficient, plotted against Reynolds number based on internal height of the pitot tube.

and $W/H=11$ are now in good agreement. Fig. 2 also shows that for any given R', C_p varies with W/H between the limits represented by the curves for $W/H=1$ and the curve for $W/H=7$ or 11.

The important feature of these results is that C_p lies below 1 for a fairly wide range of Reynolds numbers, whereas Ref. 1 shows that for a circular pitot tube C_p never falls below 1 at any Reynolds number.

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1. MACMILLAN, F. A. (1954. Viscous Effects on Pitot Tubes at Low Speeds. *Journal of the Royal Aeronautical Society*, Vol. 58, pp. 570-572, 1954.

Definition of Specific Impulse

by

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THE COLLECTED comments of Messrs. Greenwood (December 1953 and October 1954 JOURNAL), Thorne (February and October 1954 JOURNAL), and Asquith and Whitaker (May and October 1954 JOURNAL) on the definition of specific impulse in the field of rocket propulsion argue certain traditional points of view, each of which has enough merit to gain proponents but apparently not enough merit to gain universal acceptance. The appropriate definition or selection of units for specific impulse is regarded by many rocket people as being too obvious a matter to warrant examination or debate, but the continuing divergence in usage indicates to the contrary. The discussions noted above collectively raise the principal issues involved in a definition and choice of units for specific impulse. However, the conflicting nature of the recommendations made in these discussions suggests the desirability of assembling the principal issues in an emphatic form so that they will *all* be considered in any discussion of appropriate definitions and units. There may remain a divergence of opinion even when all of the issues are weighed one against the other, but the differences will have been resolved down to the relative importance of specific issues and everyone will be talking about the same things.

Received October 1954.

The comments in the references raise the following questions on the definition and choice of units for specific impulse:

1. Should the resulting value be independent of the gravitational field?
2. Should the units used be consistent in the sense of satisfying Newton's law $F=ma$?
3. Should the relation between specific impulse and effective gas velocity be emphasised, ignored or de-emphasised by the definition?
4. Should the definition be based on instantaneous performance $(F/\dot{m})$ or average performance (I/m) during the operating period?
5. To what extent should convention influence current recommendations?
6. To what extent should existing measurement techniques and facilities influence current recommendations?
7. To what extent should the choice of a definition be affected by the convenience of the resulting units?

It is this writer's opinion that the answer to questions 1 and 2 should be an emphatic "yes"; in the former instance because of the importance of rocket propulsion in flight at extreme altitude; in the latter instance simply as a matter of principle. This decision seems most

logically satisfied by the definition of specific impulse as:

$$I_{sp} = \text{Impulse}/\text{mass}$$

with units of

$$\text{lb. sec.}/\text{slug} = \text{ft.}/\text{sec.}$$

or other units of velocity. This decision seems to resolve the issue in question 3 by emphasising the equivalence between specific impulse and effective gas velocity. Since the practical significance of specific impulse is almost always manifested through the effective gas velocity factor in the familiar thrust equation $F = \dot{m}\, u_E$, the equivalence of I_{sp} and u_E seems deserving of this kind of emphasis when defining I_{sp}.

With regard to question 4, it would seem to be sufficient to note that specific impulse defined as impulse/mass is a *mass* average of the specific thrust and that the two quantities are nearly equal in most operational units. On the rare occasions when they are not equal, the effective gas velocity u_E is variable during the operating period. Then the specific thrust becomes a measure of u_E while the specific impulse becomes a measure of average u_E with respect to mass of propellant used.

With regard to question 5, there does not seem to be a real convention to follow in the present problem, so that any otherwise logical selection seems to be justified. Question 6 poses a problem which is not unique to the present issue, and seems to have no uniformly acceptable solution. It seems safe to assume that the people in England and the United States who measure specific impulse by static firing rockets will continue to report results in lb. force sec. per lb. mass (or lb. weight). It does not seem that this practice should be a determining factor in definition of the physical concept; that is, the requirement for a conversion of the test engineer's units to units of ft./sec. does not seem to be an inconvenience warranting adoption of units whose significance derives primarily from the experimental measuring technique.

Question 7 seems subject to arguments similar to question 6. Units are usually accepted as a consequence of definition of a physical concept, rather than a basis for definition. In the present case, the suggested units of ft./sec. do not seem unduly complicated.

A Method of Rapidly Estimating Propeller Moment

by

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IN a Technical Note published in the April 1954 issue of the JOURNAL an approximate equation was presented for calculating the propeller moment of a helicopter rotor at the project stage, the solution to which could be obtained from two graphs. Unfortunately these graphs were incorrectly calculated, and the error was of such a nature that it was not detected when the method was checked against two existing rotors. The correct graphs (Figs. 4 and 5 in April JOURNAL, p. 301) are now given for the equation (p. 301).

$$\frac{-M_{C.F.}}{KT_R R c_0^{\,3} w^2} = A\theta_R - B\theta_T.$$

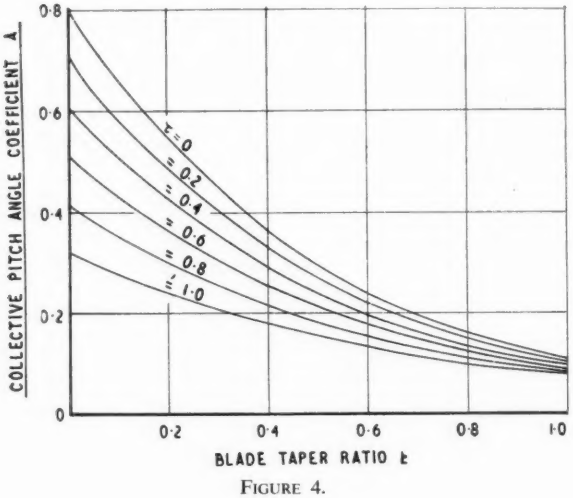

FIGURE 4.

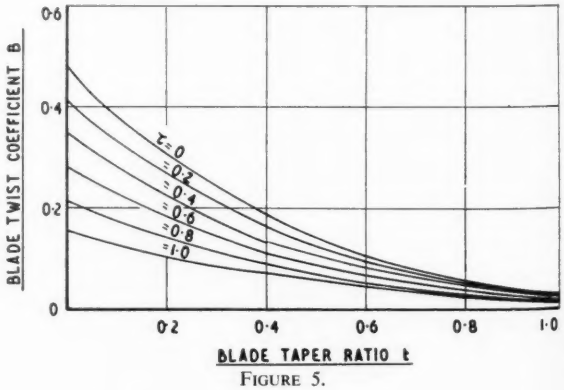

FIGURE 5.

ERRATUM—Page 728 (October)

The Flexural Centre or Centre of Shear

It is regretted that the contribution on p. 728 of the October 1954 JOURNAL was attributed, in error, to Professor J. A. Jacobs; it was in fact received from PROFESSOR W. L. SCHWALBE, Professor of Theoretical and Applied Mechanics, College of Engineering, University of Illinois.

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Reviews

AERODYNAMICS. *Selected topics in the light of their historical development. Theodore von Kármán. Cornell University Press, Ithaca, New York. Oxford University Press, Oxford, 1954. 194 pp. illustrated. 38s.*

That I should be reviewing a book by a master aerodynamicist calls for some explanation. I am a not-so-tame mathematician who has spent much of his life listening to aeronautical engineers and aerodynamicists giving explanatory talks about natural and artificial winds. I have not always understood their windy explanations. I am reviewing this book from an historical point of view to avoid the supersonic bangs I should hear if I criticised von Kármán's aerodynamics. Von Kármán would forgive me, but the others would not.

Pointing out that some branches of theoretical physics "lend themselves to speculation on the origin and true nature of the universe, others to the questioning of philosophical beliefs," the author adds, "We aerodynamicists were always more modest and did not attempt to change basic beliefs of the human mind or to interfere with the business of the good Lord or Divine Providence!"

He begins his history with the period of legends about flying, and points out that the legends do not contain much of use to future designers. "We have, for example," he writes, "the myth of Daedalus and Icarus. The only technological factor here is that the fliers did not know about heat-resistant materials; the aerodynamic aspect of the flight is not discussed."

High tribute is paid to Sir George Cayley. "He clearly defined and separated the problem of sustentation . . ." and "made certain statements that show his keen observation of the influence of streamlining on drag."

Eighty years after his death Cayley's notebook was found and published. In it Cayley had drawn an outline which he asserted was the form of a body of least resistance. "It is interesting," writes von Kármán, "to learn that the shape of his profile almost exactly coincides with certain modern low-drag aerofoil sections. (*See* N.A.C.A. 63A016 . . . LB0016) . . . the principle of the airplane as we know it now, that of the rigid airplane, was first announced by Cayley." Diagrams of Cayley's form and the aerofoil are given in this book.

I think the author is not correct in his belief that Alphonse Penaud was the first to make a model successfully stabilised by a horizontal tail surface at the rear. Cayley, in his paper of 1809-10 in *Nicholson's Journal*, discusses the use of movable horizontal and vertical rudders for a power machine.

I was very glad to read the high praise the author gives to Lanchester. He met him in 1912 in Cambridge, "and he showed me about, driving his own car along the narrow English roads at a speed that was rather frightening . . . and I felt a little uneasy discussing aerodynamics at such speed, but it did not seem to affect Lanchester. He was multisided and full of imagination."

Von Kármán points out that Lanchester was the first man to attack the problem of a wing of finite span, leading to the wing tip vortices now so familiar; and the first to point out that the kinetic energy of the downwash field represents the work necessary to obtain sustentation. He ranks Lanchester with Wilhelm Kutta and Nikolai Joukowski and adds that he went further than either and was the "first to recognise the importance of the aspect ratio of the wing in connection with the work required for sustentation."

As a pupil of Prandtl, von Kármán recalls the meeting of the two men in Germany and the discussion on their mutual interests. These pages are clear and significant. "Everyone talked only of 'Prandtl vortices' and the 'Prandtl wing theory.' Lanchester, at the end of his life, was quite embittered because he felt his contributions were not adequately recognised." Von Kármán quotes from Prandtl's Wilbur Wright Memorial Lecture. After saying that Lanchester's treatment was difficult to follow, Prandtl continued "only because we had been working on similar lines were we able to grasp Lanchester's meaning at once. At the same time, however, I wish to be distinctly understood that in many particular respects Lanchester worked on different lines than we did, lines which were new to us, and that we were able to draw many useful ideas from his book."

I had many talks with Lanchester and knew how embittered he was by the lack of recognition from his own countrymen. In 1936 he gave me a confidential memorandum on his work in aeronautics which clearly sets out the position. Here I must give credit to A. R. Low who so consistently, in private and in public, defended Lanchester and extolled his real greatness, the recognition of which was so long delayed.

In discussing stalling von Kármán says, "One can make a bird stall if one has some knowledge of aerodynamics. I often tried to do this with seagulls on the shore of Lake Constance. I had bread in my hand and as the birds tried to get it, I slowly withdrew my hand. Then the birds tried to decrease their speed to get it, which required an increased lift coefficient. Several times, apparently, the birds exceeded the critical angle of their wings and stalled."

Discussing the speed of sound and flight at that speed, the author writes, "We call the speed range just below and just above the sonic speed—Mach number nearly equal to one—the transonic range. Dryden and I invented the word transonic. We had found that a word was needed to denote the critical speed range of which we were talking. We could not agree whether it should be written with one *s* or two. Dryden was logical and wanted two *s*'s. I thought it wasn't necessary always to be logical in aeronautics so I wrote it with one *s*. I introduced the term in this form in a report to the Air Force. I am not sure whether the general who read it knew what it meant, but the answer contained the word, so it seemed to be officially accepted."

"When *I* use a word," Humpty Dumpty said, "it means just what I choose it to mean—neither more nor less."

"The question is," said Alice, "whether you *can* make words mean so many different things."

"The question is," said Humpty Dumpty, "which is to be master—that's all."

I would have said von Kármán, myself.

It is only while going through the sloppily-called sound barrier that von Kármán has any qualms, and not many of those if the power is great enough to get through quickly. "If we have suitable engines," he declares, "supersonic flight will be rather common." For all those explainers and readers of explainers of sonic bangs, I

recommend the explanation to end all explanations given by the author in the chapter on supersonic aerodynamics. At the end of this chapter is quoted that grand article by Professor C. D. Fulton in *Aviation Week* on Breaking the Sound Barrier. Some may remember the ending, " A few seconds later we heard the crash as she hit the other wall. They never found a single screw. Tony took up basket weaving and I went to M.I.T."

The author discusses a simple case of flutter that has the character of a resonance, and goes on to say, " The phenomenon of resonance is cleverly used by people predicting hidden processes with a pendulum. They predict, for example, the existence of water or ore beneath the ground. They tune the pendulum to the frequency of their pulse, so that the slightest movement of their hand causes the pendulum to oscillate with considerable amplitude. Our simple flutter case is based on a similar principle."

I don't know whether a fair deduction is that water diviners make bad seaplane pilots.

Von Kármán tells several amusing stories of the language difficulties which sometimes arise in international relationships.

" In 1945 a group of American scientists were engaged in collecting German papers and documents produced during the war. The list of German papers was translated into English by an American sergeant. One of my collaborators found, in the list of papers on aerodynamics, one titled ' Resistance of Under-nourished Bodies.' This was the sergeant's rendering of the German translation of my paper on ' Resistance of Slender Bodies.' "

In the last chapter von Kármán is perhaps at his most interesting, for he asks the questions, with an engaging simplicity of words, which are the most difficult to answer. Often he appears to me to have that high intelligence and intuition of the child before it is inhibited by teaching methods which invade its peace of mind.

" Most evident in the history of flight during the last fifty years is mankinds' yearning for speed. We often hear of new speed records but seldom hear anyone question why it is necessary to travel so fast. Who knows whether the world would not be happier without the great speeds at which we now move?"

I particularly like his own comment, " Young students with athletic ability may have brilliant scientific minds and still believe that to jump two inches farther than anybody else is an important contribution to human progress!"

The pages on the economics of speed are of great interest and the diagram from his paper (with Gabrielli), read in 1950 before the American Society of Mechanical Engineers, strikes one again as having a significance not yet widely grasped. The diagram appears to be a preliminary test of some value to find the economic speed for a specific loading per horse power, assuming that speed is proportional to that loading. Even the horse is discussed!

In this chapter the author presses that " engineering education should not only transmit experience from generation to generation, but should be based at all times on the old and new developments in fundamental sciences." His discussion of Rankine's work, here and in other chapters, emphasises this point. Rankine's contribution to the solution of aerodynamic problems is great. As an example, in 1870 he was writing on the state of a gas before and after a shock wave, correcting attempts to do so already made by Riemann.

The choice between various power systems is discussed at some length. The author comes down in favour of the turbo-prop, " at least for a few years " but " I have great confidence in the future of jet planes in the commercial field, although their higher fuel consumption and excessive noise are still difficulties to overcome."

When it comes to space travel von Kármán is finally not in favour of present forms of rocket travel. " It appears to me that the use of nuclear energy will make the rocket so much more efficient that serious attempts to build a space ship should await the advent of the nuclear rocket."

Although he is not a believer in reckless promotion of space travel schemes, and says so, yet " On the other hand, I think that the ' respectable ' scientific and engineering societies should not close their doors to the astronauts or the pages of their journals to papers dealing with the problems of space travel."

It was Elizabeth Barrett Browning who wrote, " Since when was genius found respectable?" I feel, with von Kármán, that many present day scientific and engineering societies might take note of the words of the poet.

There is a moving dedication to this book. " To the memory of my sister Josephine de Kármán whose devoted companionship secured for me the peace of mind necessary for scientific thinking."

The book is worthy of the tribute to a woman who was as great in her way as her brother is in his. I am glad to have known them both.—J. LAURENCE PRITCHARD.

MÉMOIRES SUR LA MÉCANIQUE DES FLUIDES. *Offerts à M. Dimitri P. Riabouchinsky. Publications Scientifiques et Techniques du Ministère de l'Air, Paris, 1954. 443 pp. Diagrams. In French. 3,000 fr.*

This volume pays tribute to fifty years of research, at Koutchino and the Sorbonne, by the distinguished scientist Dimitri Riabouchinsky. It consists of a regrettably brief description of his work, and of 39 papers by various authors covering a wide range of hydrodynamic and aerodynamic problems: 19 of the papers are in English, 16 in French, three in German, and one is in Italian.

In his paper on minimum virtual mass, Busemann makes two remarks which perhaps epitomise the spirit of much of this volume. He points out that " a proper use of simple integrable cases goes a long way towards the understanding of the involved problems of modern aerodynamics, and underlines the mastership of human brains over the computing monsters," and that " the problem of minimising virtual mass . . . has a certain entertainment value like other mathematical games and gives satisfaction by showing ' nature's ' own solution for more and more man-made auxiliary conditions." I cannot pretend to have read all of these mémoires, nor to have understood all of what I did read, for much of the entertainment takes place at a high level of mathematical sophistication; but I hope that the following brief descriptions of some of the papers which I personally found of particular interest will give some indication of the nature of this volume.

There are two papers on developments of Riabouchinsky's hydraulic analogy, by D. R. F. Harleman and A. T. Ippen and by E. V. Laitone: these authors propose considerably different values of the optimum water depth but both display sensible experimental results. C. Heinz tackles the problem of the oscillating body of revolution in linearised supersonic flow—but not by slender body methods, of which he makes no mention. The conversion of the resulting integral equations into a numerically tractable form is a formidable piece of theory. W. P. Jones outlines recent developments at the N.P.L. for the

semi-empirical calculation of aerodynamic derivatives for two-dimensional wings. J. K. Lunde derives a general expression for the wave resistance of a slender ship moving with variable speed along a canal of finite depth; he uses a source-distribution method developed by T. H. Havelock. In a short and attractive paper G. I. Taylor deduces the approximate curve followed by an initially vertical jet acting as windscreen to a horizontal flow: the jet is assumed to have infinitesimal thickness everywhere. S. Vladimirsky, using Riabouchinsky's extended complex numbers $(x+i_\varepsilon y$, where $i_\varepsilon = \pm\sqrt{(\varepsilon)}$ and ε is a continuous function of x and $y)$, obtains the rotational incompressible flow about a circular cylinder such that the tangential (as well as the normal) velocity vanishes at the surface, the flow at infinity being uniform.

The book is impeccably printed. It can be freely recommended to those who study fluid motion for the joy of the chase.—L. E. FRAENKEL (Imperial College).

TITANIUM AND TITANIUM ALLOYS. *John L. Everhart. Reinhold Publishing Corporation, New York. 1954. 184 pp. Diagrams. 24s.*

By way of introduction be it remarked that there are about 90 stable chemical elements. Over 70 of them are metallic. The engineer, faced with this galaxy from which to choose, seems to have suffered and perhaps continues to suffer from an *embarras de richesses*. Even today, for the vast majority of his mechanisms and structures, he uses alloys of only four metals—copper, iron, aluminium and magnesium.

Familiarity with the first has existed for at least 5,000 years. With the second, it has endured for some 2,000 years less. Aluminium and magnesium, on the other hand, have been known for only about a century and a quarter. The former has been extensively employed for two generations. The latter has, however, been an engineering material for only about half this time.

This is a strange story allowing of much speculation, but that of titanium is perhaps even stranger. At the time of the Napoleonic wars, the existence of this metal was known to very few. By the outbreak of the Second World War, it was known to many, but very few indeed had any use for it. Today, after Government expenditure, chiefly, but not wholly, in the United States, of a magnitude dwarfing that on all schemes to grow ground-nuts in a near desert and to induce British hens to do their duty by the Old Country in a new and tropical one, it is being produced at an ever expanding rate. Currently this is about 6,000 tons a year, but it is estimated, perhaps somewhat wishfully, to attain over 20,000 tons by the end of 1956.

The Cinderella-like neglect of titanium from 1789 to 1940, followed thereafter by a pouring out of treasure vastly in excess of anything achieved by the most infatuated of Fairy Princes, is a *volte-face* indeed. It demands an explanation and this is easy to give. In the years of neglect virtually little or nothing was known of the metal. Now, however, when Governments, nervously if not in panic, gird up their loins for a feared Armageddon, the metal is known to have something, and perhaps more than something, the others have not got. It can, in restricted, though in important fields, strengthen the very sinews of war and will surely thereafter have industrial uses.

No longer do the secrets of titanium lie hid and unsought. In less than twenty years between four and five thousand papers and technical articles have been written about it. Its unique combination, over a considerable temperature range, of physical, chemical and mechanical properties are plain for all folk to see, but, until now, no book in English has been written about it. Admittedly the first work solely devoted to the metal is a very small one, though its price, like that of all American publications in this country, is rather high. It contains about 30,000 words and costs 24s. It makes no pretence to be other than superficial. Its ten chapters cover a wide field. They contain few, if any inaccuracies, though as regards fabrication, particularly machining, some, with practical experience, may hold views differing from those of the author. The book can nevertheless be recommended as a good introduction to its subject, but, because of feverish research in many countries, it will not long remain up-to-date. It can now, however, serve a very useful purpose.—P. L. TEED.

STRATEGY FOR THE WEST. *Marshal of the R.A.F. Sir John Slessor, G.C.B., D.S.O., M.C. Cassell & Co. Ltd., London, 1954. 162 pp. 9s. 6d.*

A Marshal of the Royal Air Force speaks with an authority on air matters to which only the event he predicts will testify as to the correctness of his strategic guess. Sir John Slessor admits, " My thinking is obviously conditioned by my professional background," and adds, " The book is written in the hope that it may contribute to an objective appraisal of the true military situation in a critical period of history."

To put the book in a nutshell, the author states on page 20, " Effective over-all defence is just as impracticable for our only potential enemy as it is for the West," a thesis he rubs home at intervals until, on page 109, he writes, " We must be able instantly to deliver a crushing counter-attack upon aggression at its source—not merely at its airfields, its launching sites, and submarine bases, or its armies in the field, but at the heart of the aggressor country."

Although it is not difficult to say Bo to a flying goose, it is hard to fly on the wings of the wind with such an eloquent and metaphorically-minded Marshal. For has he not declared here and elsewhere that the hydrogen bomb is the great deterrent? When dropped by us or the enemy? When is rather an important word, for the aggressor country will have started the World War with the bomb. Sir John Slessor calls Vannevar Bush to his aid, " One element of our strength should indeed be ready and straining at the leash. That is the retaliation force."

But there is no defence, whether you are an aggressor or not, especially if the hydrogen bomb, the great deterrent, proves to be no deterrent. Either side may drop a few or many bombs, and where do you get? Not so far as will matter to either of you.

Sir John Slessor, on pages 145-47, suggests a treaty on the Locarno model, so that British and American forces may withdraw from Europe, whether Russian forces do or do not. Of his proposed treaty he writes, " It must at the same time involve a firm commitment to the effect that any aggressor would instantly be subjected to overwhelming force, of a nature that would almost certainly deter him from aggression, and would at least bid fair to destroy him if he did attack."

There are nine clauses in the author's new Locarno, of which the ninth is the most astonishing. This clause declares that " in the event of aggression by any signatory against another (or by any of the three Soviet bloc powers, if they do not adhere) the aggressor will instantly be subjected to the full weight of Anglo-American atomic air power."

Well, there it is again, without any frills.

" There are risks in this of course; we should have to steel ourselves to meet a sudden, treacherous attack at any

moment during the procedure." The procedure (page 150) being to warn first of all the potential aggressor, as the latter is creating a situation—such as the Nazi pressures on Czechoslovakia, Danzig and Poland before 1939—by radio warnings and pamphlets, " telling them clearly what will happen if their government use force and warning them to evacuate a specified list of cities and other objectives, from which should be selected the first targets for attack should that be necessary."

When a lady said to the Duke of Wellington, " What a glorious thing must be a victory, sir," he replied, " The greatest tragedy in the world, Madam, except a defeat." Francis Bacon put it another way, " Pyrrhus," he wrote, " when his friends congratulated to him his victory over the Romans, under the conduct of Fabricius, but with great slaughter of his own side, said to them again, ' Yes, but if we have such another victory, we are undone.' "

This book is stimulating, interesting, provoking and reasonable in those parts with which you disagree or agree. I wish I could agree with more than I do.

" But fear, the last of ills, remain'd behind
And horror heavy sat on ev'ry mind."

Fear and horror are not modern deterrents.—J. LAURENCE PRITCHARD.

THEORETICAL ELASTICITY. *A. E. Green and W. Zerna. Clarendon Press, Oxford. 1954. 442 pp. Diagrams. 50s.*

The authors of this book have used the tensor and vector notations throughout and consequently readers, unfamiliar with the use of tensors, will find the book rather unfriendly at first as the basic equations of elasticity may not be recognised. This effect is aggravated by the choice of symbolism which differs from that in common use by elasticians. However, as compensation, the authors have provided an excellent first chapter of some 50 pages dealing very effectively with the mathematical preliminaries, including symbolism.

The first main topic dealt with is that of finite deformations and this occupies two chapters, the first giving the general theory and the second giving the solution of a number of particular problems. Most of these examples deal with incompressible isotropic bodies, the solutions being of interest to applied elasticians dealing with flexible materials, such as rubber, having a value of Poisson's ratio approaching one half. Chapter 4 gives a theory of small deformations superposed on finite deformations, and this is used to solve certain unsymmetrical deformations such as small bending of a stretched plate.

The next five chapters deal with the second main topic of the book, which is the application of complex variable methods to two-dimensional problems using the classical infinitesimal theory. This theory is given in Chapter 5, and there are also chapters on plane strain, plate theory, and plane problems for both isotropic and aeolotropic bodies. The examples dealt with in these chapters include stretching and bending of plates, locally applied forces on semi-infinite plates, cracks, polygonal holes in plates, infinite wedges, overlapped circular holes, and notches.

The final five chapters are devoted to the third main topic which is that of shells; the general theory is given together with the simplifications which result when the shells can be regarded as being thin. Some examples are given, mostly concerned with thin shells.

The aeronautical engineer, as an applied elastician, will find the applications of some of the theoretical problems considered to be very obscure, and would wish for more reference in the text as to the practical significance; this however cannot be regarded as criticism of a book on theoretical elasticity. The book is well written, the arguments being very clear, and the printing and layout is of the high standard which readers have come to expect in present-day text books.—P. J. PALMER (University of Birmingham).

" MACH ONE." *" Mike " Lithgow. Foreword by Charles Gardner. Allan Wingate, London 1954. 151 pp. Illustrated. 12s. 6d.*

There seems a nice rivalry between the Hawker and Supermarine Companies in the production of competing fighters, which now is being matched by the ability of their respective Chief Test Pilots not only to make sonic bangs but to write their personal flying experiences in similar books which undoubtedly will attract the hero-worshipping young—and even Charles Gardner in the case of Mike Lithgow. Perhaps not surprisingly it is from the Foreword that more can be visualised about Lithgow than all the rest of the book, for the latter is written in so spartan and factual a style that everyone will echo the wish that he had made the words come out a little more " twopence coloured." If one is rash enough to break into print and sufficiently diligent to write a book, then it is as great an aesthetic error to understate as to over-state, for the essential purpose of all good writing is to hold the interest of the reader, and this can only be done by stirring his emotional response as well as his intellectual appreciation.

The title *Mach One* leads the hopeful reader to expect a book disclosing human response to flight at or near shock wave speeds. In the lack of this he will be disappointed, for most of the book deals only with the history of events comprising Lithgow's Service and civilian career. There is, however, a sober though readable chapter explaining to the layman the necessity of the power controls in relation to the aerodynamics of transonic flight, and there is another on pressurisation, but these are expositions which might have been written by a technician rather than a test pilot. What everyone would like to know is what all this means in terms of a pilot's reactions and thought.—HARALD PENROSE.

FLEET AIR ARM. *Lt.-Cdr. P. K. Kemp, R.N.(Ret.), F.R.Hist.S. Herbert Jenkins, London, 1954. 232 pp. Photographs. 16s.*

This is a book which clearly needed to be written and Lieut.-Cdr. Kemp has written it very well indeed. It follows the now familiar (but none the less excellent) technique of tracing history by describing a series of events chosen as typical and characteristic of the period and subject. This method is designed to make the book " readable " and of wide appeal and this objective Lieut.-Cdr. Kemp has achieved without doubt. Much of the book is of great interest by any standards. Much of it will help the general reader to understand something of where " the air " fits in with " the sea," which is a subject often imperfectly understood not only by the layman but also by many who should and must understand. Finally there are parts of the book which are moving and inspiring in the simple description of deeds done with cold and deliberate bravery in the face of almost every difficulty and hazard.

Lieut.-Cdr. Kemp is the Admiralty Archivist and he was thus in a unique position to write this book. He himself was a Submarine officer and there are, to the purely aeronautical reader, a few " gaffes." That magnificent old warhorse (or seadog) the Swordfish is accused of having a rotary engine—God knows it had enough to contend with without that—and then the author neatly fobs off the

Barracuda as "of American design." In the caption to a photograph of a carrier, her windbreaks are described as crash barriers and there are several other such slips which one would have thought could have been sorted out for the author by some Fleet Air Arm proof reader.

Perhaps the author's most difficult task was in dealing with the period of divided control of the F.A.A. between the Admiralty and the Air Ministry. He deals with this on the whole fairly and with restraint, but it is a pity that he chose to describe as a "naïve document" what was perhaps one of the most prescient statements ever produced by a government committee. The relevant quotation from the report (August 1917) of the committee headed by Lloyd George and General Smuts is there for all to see on page 106 and the meat is contained in the first paragraph. Certainly for the successful formation of a third and independent service ruthless measures were necessary at that time. Once the Royal Air Force was firmly established the Navy in due time regained control of its own Air Arm; perhaps the Navy suffered in the process but it is difficult to see how events could have been shaped in any other way. Many years later the Americans followed where we showed the way.

"Fleet Air Arm" should be read by anyone even remotely connected with service aviation, and certainly by all who interest themselves in human endeavour.—J. K. QUILL.

ELECTRICAL IGNITION EQUIPMENT. *F. G. Spreadbury. Constable, London, 1954. 227 pp. Illustrated. 25s.*

The author has made an attempt to deal with the theory and practice of spark ignition equipment, and although the book is generally well-written and illustrated, it is hardly comprehensive enough for the potential ignition designer, yet it contains more ignition theory than would be needed by automobile engineers and other users of ignition equipment.

Further, it would have been better if equipment design matters could have been dealt with in one chapter, rather than in two. For instance, the design of the magneto magnet is described in Chapter IV, whereas the design of the remainder of the magneto is covered rather briefly in Chapter V.

This chapter is somewhat disjointed and could be of little use to the potential designer. As an example, magneto bearings are dismissed in a very short paragraph, yet more attention has been given to the design and fitting of such bearings over the past few years than to many of the other individual components of the magneto. Cam lubrication is inadequately dealt with.

The author describes one particular coil construction as indicating general practice. Different manufacturers use different design features and materials, and several types should have been described and reasons for their adoption given.

Perhaps the most outstanding omissions in the book concern references to pioneers in the expounding of ignition theory and the putting of this theory into practice. No book on ignition can be complete without reference to J. D. Morgan, A. P. Young and H. Warren, and E. A. Watson. It is also a pity that representative sectional drawings of some of the latest aircraft magnetos were not included.—R.H.W.

JUSQU'AU BOUT SUR NOS MESSERSCHMITT. *Général Galland. (In French). 277 pp. Illustrated. Robert Laffont, Paris, 1954. 690 fr.*

This is yet another autobiography written by one of the military leaders of the last war, but it has the added interest of being written by one of the senior officers of the Luftwaffe. The actual book reviewed is a French translation by Max Roth.

Looking through the preface written by the ex-Commandant of the French Fighter Group stationed in England during the War, one's interest is further aroused by the statement, which is claimed to have been printed during 1943 in the Official Bulletin of the R.A.F., under a photograph of General Galland, saying: "Take care, if you meet him, this man is dangerous"!! If this warning was actually given, one wonders whether our pilots were given special apparatus to enable them to see the features of their opponents during aerial combats, or whether they had definite instructions not to shoot until they saw the white of the enemy's eyes!!

This book gives details of the flying career of one of the most brilliant officers of the Luftwaffe, from the time he entered the Lufthansa in 1932 against terrific competition, through the various parts of his training: the reader is given a close view of the way the then leaders of Germany contrived to build an air force in spite of the restrictions imposed by the Versailles Treaty, and mainly because of the co-operation of the Italians . . .

The author then completed his training with the Condor Legion in Spain, which he soon led; with the occupation of Czechoslovakia, Poland, Belgium and France. Then comes the Battle of Britain where Galland scores numerous victories, gains promotions, and collects decorations of ever increasing importance. In this connection the author gives us some clues as to the mentality of the leaders of the Third Reich, and their somewhat childish spirit of competition when awarding gold and diamond covered decorations to victorious pilots.

Soon the Luftwaffe meets the ever-increasing punch of the R.A.F. and, in due course, of the American Air Force and the Luftwaffe then begins to meet defeat after defeat mainly, so General Galland states, because Göring and Hitler were placing the utmost priority to the production of bombers, to form a retaliatory force, instead of producing fighters for the defence of Germany.

As the Luftwaffe suffers devastating blows on both the Eastern and Western Fronts, Galland becomes more and more bitter about the conduct of the war and now appears to be very conscious of his general disagreement with it. But one cannot help being somewhat surprised that Galland, who was then their C-in-C, was willing to be always overruled and accepted instructions with which he disagreed so much.

Finally after the defeat suffered by the Luftwaffe at the Battle of the Ardennes, Galland was relieved of his post and given command of a small group testing the Me. 262.

This book is interesting and quite entertaining. Unfortunately the arguments throughout the book lack the necessary supporting figures and other data, and one would have appreciated more details as to the actual German aircraft production, personnel training and wastage due to various causes: most of the figures quoted in the book appear to have come from Churchill's memoirs.

This French translation is very well written and, apart from a few minor spelling errors, well printed. Excessive use is perhaps made of the pilot jargon, especially at the beginning of the book and this may make reading difficult to someone not very familiar with the language.—J. A. KIRK.

THE DYNAMICS AND THERMODYNAMICS OF COMPRESSIBLE FLUID FLOW. *Vol. II. Ascher H. Shapiro. Ronald Press, Nw York, 1954. 534 pp. Diagrams and photographs. $16.*

Most of the general remarks in the review of Volume I (May 1954 JOURNAL) apply equally to the second volume. The book is essentially a reference work for *engineers, i.e.* the emphasis is on methods and theories that give results useful to the engineer, and the author does not scorn empirical theories if the results are useful. In sections where space does not permit a detailed exposition (*e.g.* in considering hypersonic flow) the author has collected the more important useful results, often without proof, and given references to the papers where details can be found. The references have been carefully selected and are the really useful ones. There is an adequate subject index.

The first three chapters of this volume deal with supersonic flow in three dimensions, and with hypersonic flow. (These chapters complete Part V of the book, started in the first volume.) In the first of these chapters, on axially symmetrical supersonic flow, the exact solution for flow past an unyawed cone is followed by a discussion of linearised theory for an unyawed body of revolution. This is followed by an account of the method of characteristics, with emphasis more on the method of calculation than on the mathematical theory. The chapter concludes with a brief discussion of supersonic inlets and some miscellaneous flows. In the second and third chapters, wings of finite span and hypersonic flow are considered. These subjects have now become very large ones and, apart from initial discussions of general principles, the chapters consist mainly of comparatively brief accounts of the useful theories and the results obtained from them. Some comparisons with experiments are also made.

Part VI deals with mixed subsonic-supersonic flows. In the first chapter, on the hodograph method, the hodograph equations are derived, some particular solutions are given, and limit lines are discussed. In this chapter the main theme is the bearing of the hodograph solutions on the possibility of shock-free mixed flows, with deceleration from supersonic to subsonic speed. In the next chapter the "transonic approximation" is introduced, leading to the transonic similarity law. The equations for oblique shocks and for Prandtl-Meyer expansions are expressed in "transonic similarity" form and applied to calculations on two-dimensional aerofoils. Some further theoretical results for transonic flow are given, but for obvious reasons there are few comparisons with experiments. In a further chapter, dealing with experiments on aerofoils at transonic speeds, some comparisons are made with the transonic similarity law. Although most of the results given refer to two-dimensional flow, the effects of sweepback and finite aspect ratio are considered briefly. Methods of calculating the positions of detached shock waves are also reviewed. There is a further discussion of the possibility of shock-free transonic flow and a brief mention of shock-wave boundary-layer interaction.

Part VII gives an account of unsteady one-dimensional flow. In the first chapter of this part, the equations of motion are derived for an inviscid gas without shocks. The linearised equation for small perturbations is then introduced, and its use illustrated by examples. In the next chapter the perturbations are no longer assumed to be small, the method of characteristics is described, and a number of illustrative examples are given. The final chapter of this part deals with unsteady one-dimensional shock waves, starting with a transformation of the previously derived stationary shock formulae, and going on to a direct analysis of moving shocks from the basic equations of continuity, momentum, and energy. The simplifications that are introduced by assuming the shocks to be *weak* are also considered. Flow in a shock tube and various effects of interaction and reflection are considered.

In conclusion, Part VIII deals with boundary layers. The first chapter, on the laminar boundary layer, starts with a general discussion of the importance of heat transfer, the assumptions of boundary-layer theory, and the orders of magnitude of various quantities. The equations are then derived, and the simplifications obtained by assuming a Prandtl number of unity are explained. Flows with arbitrary Prandtl number and heated or cooled boundaries are then considered and some comparisons with experiments are made. The chapter on the turbulent boundary layer is rather unsastisfactory. Instead of attempting an analytical approach based on such concepts as mixing length, eddy viscosity, and "turbulent Prandtl number," the author might have been better to acknowledge the lack of a satisfactory theory and approach the subject from the available experimental results. The final chapter of the book deals briefly with pipe flow, normal shocks in ducts, and shock-wave boundary-layer interaction.

A remarkable feature of the book is that it includes many of the latest advances in the subject; there are numerous references to papers published in 1953 and some even as late as March 1954.

As in the first volume, most of the mathematics is not difficult, and should be easily understood by any engineer who would use the book. The two volumes together form a valuable reference book for the internal or external aerodynamicist.—W. A. MAIR.

DEVELOPMENT OF THE GUIDED MISSILE. *Kenneth W. Gatland. Second Edition. Iliffe, London, 1954. 292 pp. Illustrated. 15s.*

The first edition of this book was reviewed in the Journal of December 1952, and this new edition, the second, certainly is "completely revised and greatly enlarged." There are now more than double the number of pages and of illustrations. New chapters have been added, dealing with problems of propulsion, research into rocket techniques and requirements, and post-war work on guided bombs. Of particular importance is the detailed survey of Russian potentialities for long-range rocket development. Appendices give details of the telemetering equipment used in British missiles, and photographs of over 40 notable rockets from various countries. The table of characteristics now provides data on 140 powered rockets from eight countries.

The price has naturally increased—from 10s. 6d. to 15s. 0d.—but it is still reasonable for such an informative book.

ENGINEERING UNITS AND THE STROUD CONVENTION. *F. W. Thorne and A. C. Walshaw. 29 pp. 6 figures. Blackie, London, 1954. 3s. 6d.*

The purpose of this booklet is to present a simple method of overcoming difficulties concerning units and dimensions when developing and using formulae. This it does, clearly and concisely, and with most useful examples and exercises. The booklet is written by the Professor and Assistant Professor of Applied Mechanics at the Royal Naval College, Greenwich, and is intended for students of applied mechanics and engineering science. It will be welcomed by all who have ever had to distinguish between lb. mass and lb. weight, and particularly those who

have been following the recent correspondence in the Journal on the definition of specific impulse.

GAUGE MAKING AND MEASURING. *National Physical Laboratory. Notes on Applied Science No. 5. H.M.S.O., 1954. 80 pp. Diagrams. 3s.*

This booklet is one of a series intended to provide, for industrialists and technicians, information on various scientific and technical subjects which is not readily available elsewhere. The first edition was prepared by the staff of the N.P.L. during the Second World War as an aid to firms entering the field of gauge making for the first time, but experienced gauge makers may also find it useful to have the information available in a convenient form. The booklet should also be a help to students taking Metrology as a subject in the National Certificate Examinations in either mechanical or production engineering.

FUNDAMENTALS OF RADAR. *Stephen A. Knight. Second Edition. 150 pp. 113 figures. Pitman, London, 1954. 15s.*

This is the second edition of a book, first published in 1947, intended as a basic survey of the principles underlying radar, and calling for no specialised radio knowledge. Parts of the original text have been revised and new material, for example a chapter on waveguides, has been added to bring the book into line with recent developments.

VIEW FROM THE AIR. *Hugh Fosburgh. Collins 1954. 254 pp. 12s. 6d. net.*

The Upstairs Maid is a B.24 engaged in the Pacific theatre. Her Pilot is a peacetime journalist, the co-pilot is a country boy, the bombadier is a shiftless type whose wife will have little to do with him, the navigator is a young man with a religious family. Need one say more? Nevertheless, "View from the Air" is quite a readable novel and one does not have to digest large lumps of psychology and introspection.

TIME ENOUGH TO LIVE. *D. Brennan. Martin Secker & Warburg 1952. 231 pp. 10s. 6d.*

This is another of those R.A.F. novels which all run on the same lines. The bomber base and its denizens and the lives they lead are described, with liberal doses of crude language (implied of course) and male/female relations (in fair detail of course) to keep the reader interested. After a while the same old slang and the same old preoccupation tend to pall and one yearns for the sustained excitement of the real-life adventures of a Clostermann or a Gibson. Will the novelist of 2053, writing of the R.A.F. in World War II be able to find a flying equivalent of Hornblower?

NO DISTRESS SIGNALS. *Winifred Brown. Peter Davis, London 1952. 248 pp. 12 illustrations. 15s. net.*

Winner of the King's Cup Air Race in 1930, Winifred Brown has since spent much of her time "messing about in boats." This is the story of her second voyage, in 1939, to Spitzbergen and the war years which she spent, with her boat, at the Saunders-Roe flying boat base in Anglesey. The book has little connection with aviation and in many ways it is the reader who might fly distress signals.

HIGHER INDUSTRIAL PRODUCTION WITH ELECTRICITY. *British Electrical Development Association 1953. 146 pp. 104 Illustrations. 9s. net.*

This is the introductory volume of the new Electricity and Productivity Series of eight books to be published by the B.E.D.A. It is not a technical book, but it is intended for the guidance of management and to give some of the more striking examples of electrical methods for increasing productivity, but since literature on both production and management is scarce it is well to have a volume or two on fundamentals to start with. Comparisons with the U.S. and British methods are drawn and the various available electrical apparatuses for speeding up production are described. The nine chapters deal with Industrial Power and Productivity, Factory Layouts and Electric Installations, Lighting for Production, Electric Motors and Control Gear, Materials Handling, Electric Furnaces and Heat Treatment in the Production Line, Welding, Electrical Testing and Inspection, and Electricity and Productivity Service.

THE ROYAL AIR FORCE. VOL. III: THE FIGHT IS WON. *Hilary St. George Saunders. 441 pp. Maps and Illustrations. H.M. Stationery Office. 13s. 6d.*

Rarely has a finer history of a brief span of years been written. Trevelyan and Arthur Bryant are masters of the modern method, but not even they have had material so stirring with adventure and packed with incident upon incident of mighty endeavour as the epic of the Royal Air Force which Denis Richards and the late Hilary St. George Saunders portray with such confident discrimination and balance. In the third and final volume the story embraces the wide growing theatre of the Second World War in the mounting tempo of 1943-1945. It moves with an implacable momentum to an inevitable end, whether the scene is the lonely waste of the Atlantic, the great sea and airborne invasion of Normandy, the battle for France and the road to the Rhine, or the Fifth Army surging throughout the length of Italy in the wake of the sullenly retreating Germans, and on the other side of the world the Fourteenth Army pressing through the drenching rains and clammy heat, beating back the Japanese until those last terrible moments when the atomic bombs fell on Hiroshima and Nagasaki—and the Second World War was over, but with victory dimmed by the shadow of new fear.

Yet though this great but concise book maps the course of war on land and sea with masterly comprehension, it is of course the work of the Royal Air Force in securing anihilating victory which makes these martial pages ring with the courage of high devotion. It is no mere tale of highlights and heroics; indeed description of raid and battle is as impersonal as it could be without losing vividness in the general picture of strategy and tactics wherein time marches towards its goal with planned attack which few of those participating could even comprehend.

This history clearly demonstrates that air domination made possible seven vital achievements in those years of war. First, it enabled Great Britain to become the base for the creation of the huge invasion force. Secondly, in Africa the Eighth Army was saved from destruction when forced to retreat, thus paving the way for the victory of El Alamein. Thirdly, in the Mediterranean sea communications of the enemy were made impossible, so that starvation and defeat of the Axis Armies in North Africa followed. Fourthly, the armies of liberation next crossed the Channel and without hindrance secured foothold on the hostile shore. Fifthly, mastery of the air was vital in the long fight against U-boats and so enabled supplies to enter this country. Sixthly, the great bomber attacks brought the enemy's industries and armies to standstill and defeat. Lastly, air superiority in the Pacific, established largely by the Americans, severed Japanese sea communications from her conquests and finally pulverised the Japanese homeland into submission.

There are many lessons inherent in this triumphant story of planning and fulfilment. Perhaps the greatest of these is that the need for sea power has not been destroyed by air power, but instead depends as much on domination in the air as it does on the sea. To a nation such as ours this is a vital fundamental, for the sailor and the airman must henceforth work side by side and fight together.

In the brief compass of a review it is impossible to do more than suggest the nature of a book, but in this great record of the R.A.F. the old familiar things are enshrined in a new light. Read of Spitfire and Hurricane, Lancaster and Sunderland, of flying bomb and rocket, of Lysanders and spy-dropping; the development of Go, Oboe and H2S; of the vast scale of our bombing and the nigh million anti-aircraft gunners Germany had to maintain in defence; of operations Diver, Dracula, Flashpoint, Herman, Mastiff, Overlord and a score of others—but in everything acknowledge the spirit of those men who flew. Young in years, they brought to perfection a form of warfare invented by their fathers who flew in " contraptions of wood and linen " —and these young men, " whether in battle against the *Luftwaffe* or the German *Reich* or quartering the skies above a convoy driving along the perilous paths of the ocean, displayed a mastery which was the admiration of the world and saved the cause of freedom. Fearless yet prudent, grim yet gay, unshaken by the caprice of fortune in all that they did, they proved themselves to be worthy descendants of that generation of whom a great queen spoke three and a half centuries before ' Even our enemies hold our nature resolute and valient, and whensoever they shall make an attempt against us I doubt not but we shall have the greater glory.' "—HARALD PENROSE.

FLIGHT HANDBOOK. *Fifth Edition. Iliffe, London, 1954. 282 pp. Illustrated. 15s.*

For the lad who still likes to keep abreast of ordinary aeronautics while studying to be a space pilot there are quite a number of well-illustrated and simple books. It is the rather older youths who are not catered for, in general books on aeronautics in all its aspects. At least, they were not until the appearance of this fifth edition of *Flight Handbook*.

Offhand it is difficult to think of any field of its subject that is not covered and though the order of chapters may seem a little weird, Gliders and Lighter-than-Air come in for their share of treatment. Previous editions of the Handbook appeared in 1945, 1943, 1941 and 1938 (a *Flight Manual* was published in 1910). The present book has 282 pages 5¼ in. by 8 in., plus several of those excellent " Flight " exploded drawings as folded plates. Probably not a book for the specialist but essential to the intelligent enthusiast and the prospective technician.

AIRCRAFT FOR ALL. *S. E. Veale. 256 pages. Illustrated. Ward, Lock, London, 1954. 12s. 6d.*

Mr. Veale has been writing books on aeronautics for a long time now but of late he has been presenting the reviewer with a problem. At what age-group is he aiming? From the other titles in the " For All " series, of which this is one, one must assume that this is a book for the A.T.C. type but I wonder if it is sufficiently technical? For younger lads it is too technical. It tries to cover all aspects of aeronautics from the historical to the specialised discussion of engines, instruments, materials and so on. However, it is just the sort of book that aunts and uncles think will be suitable for their nephew and as it is generously and well illustrated, with 100 photographs and recognition aids, the nephew will not be disappointed.

RENDEZ-VOUS 127. *Diary of Mme. Brusselmans, M.B.E. Transcribed by Denis Hornsey, D.F.C. Ernest Benn, London, 1954. 173 pp. Illustrated. 12s. 6d.*

" Rendez-Vous 127 " tells the story of Madame Brusselmans, an English-woman married to a Belgian, who, during the Occupation, worked with the escape organisation in Brussels at the receiving end of the famous Comete Line. The narrative takes the form of a diary kept by Mme. Brusselmans from the 9th May 1940 until 9th September 1944 when the Germans finally left Brussels. Mme. Brusselmans is a remarkable woman whose courage and resourcefulness were taxed to the utmost. She maintained the escape line when its members were discovered and arrested by the Gestapo and finally reconstructed it completely when she alone was left undetected. The tension and fear of her life during these years are conveyed most convincingly by this " plain, unvarnished tale " in which the reader may relive an experience which, it must be remembered, is still that of those maintaining escape routes to the free world.—P.D. & J.A.D.

TO PERISH NEVER. *Henry Archer and Edward Pine. 188 pp. Cassell. 9s. 6d.*

A story of the first tour of operations by an untried bomber crew in a Lancaster Squadron of the Second World War has possibilities, but requires a particularly gifted pen to hold attention a decade later than that in which the scene is set. The jargon is there but not the spirit—except in a rare phrase or so hinting at the play of subconscious thought in a pilot's mind as he flies immolated by the din of his engines. Had there been more of this psychological impressionism the story might have been effective, but as a work of imaginative fiction it smacks too greatly of mere reportage of actual experience. Inevitably comparison with the effortless style of Neville Shute or H. E. Bates is made, who take ordinary men and women and reveal both their kindred and the spark of their divinity.—HARALD PENROSE.

" TIGER " SQUADRON. *Wing Commander Ira (" Taffy ") Jones, D.S.O., M.C., D.F.C., M.M. W. H. Allen, London, 1954. 295 pp. Illustrated. 15s.*

" Taffy " Jones's latest book leaves one in little doubt as to the fighting spirit of those who served in the Royal Flying Corps during the 1914-1918 War and the Royal Air Force between 1939 and 1945. Practically every one of the 285 pages depicts the feelings of pilots of both Wars when engaged in determined and aggressive interludes with the enemy.

The book is divided into two parts: the first, entitled " Builders of Tradition " covers the period 1914-1918 including the formation of number 74 Squadron, and the second, the part played by this Squadron during Dunkirk and the Battle of Britain. There is a short chapter covering the period 1918-1939.

The fifteen chapters of Book I are essentially an autobiography by " Taffy " Jones, written from notes in his personal diary and describing the part he played in this famous Squadron. It makes very interesting reading and also covers the exploits of such famous fliers as Captain Albert Ball, V.C., and Major " Mick " Mannock, V.C.

Book II deals with the period of " Tiger " Squadron under its famous Commander " Sailor " Malan; the record being made up of extracts taken from the official combat reports of some of the " Few." As " Taffy " Jones says, during the Second World War he was concerned mainly with the training of fighter pilots at 53 and 59 O.T.U.s and as a consequence this part has a tendency towards an official history as distinct from the personal touch one has

come to expect in this type of writing; nevertheless, it still makes good reading.

The book is well illustrated with some twenty photographs which include sketches of famous fighter pilots made by the well-known black and white artist Captain Cuthbert Orde, but to describe it as the history of 74 "Tiger" Squadron is not entirely correct. It is an autobiography filled in which some factual reports and makes no real reference to the Squadron activities beyond the end of 1941.—R. H. LAVER.

NEVILLE DUKE'S BOOK OF FLYING. *Edited by Edward Lanchbery. 130 pp. Illustrated. Cassell. 9s. 6d.*

Here is a production which boys will appreciate, especially those who are hero-worshippers, for there is magic in the name of Neville Duke, both for them and the publisher. Whether the book was written by Neville Duke or others is not very clear, but it seems to be based on a section or two by him, and the rest made up with chapters of different authorship, making it somewhat patchy. Thus the story of the first "Thousand Bomber Raid" seems a little incongruous after the up-to-date opening of "How to Fly a Jet," nor does the book deal solely with a pilot's outlook on flying, but its eleven chapters cover among other diverse things, navigation, helicopters, carrier operations and "The Shape of Things to Come"—so that in small space the book is certainly ambitious if not a little pretentious.—HARALD PENROSE.

SOUND BARRIER. *Neville Duke and Edward Lanchbery. Sixth Edition. Cassell, London, 1954. 129 pp. Illustrated. 8s. 6d.*

This edition, the sixth, is a "completely revised and enlarged edition" of the book reviewed in the Journal of November 1953. The book has been brought up to date by the addition of information on new height and speed records, new engines and aircraft (including the aero-isodinic wing and vertical take-off developments) and there are newer, and more illustrations.

THE WORLD'S FIGHTING PLANES. *William Green and Gerald Pollinger. 240 pp. Illustrated. Macdonald, London, 1954. 12s. 6d.*

Green and Pollinger are rapidly becoming the Rawicz and Landauer of aircraft recognition.

The military aircraft (is a Varsity a fighting plane?) of 18 countries are briefly described and a good photograph and three silhouettes given of each type. Under each alphabetically arranged country its machines are in turn placed in ABC order of manufacturer but the position of such items as the Me 109 is described in the Introduction.

There are 29 U.S.S.R. planes listed, 128 British Commonwealth and over 200 U.S. There is a moral here somewhere.—F.H.S.

WIND-TUNNEL TESTING. *Alan Pope. Second Edition. John Wiley, New York. Chapman & Hall, London. 511 pp. Diagrams and photographs. 68s.*

This is the second edition of the book received in the September 1948 JOURNAL. It is much increased in size—and naturally in price—and contains new chapters covering testing at near sonic, transonic, supersonic and hypersonic velocities. The testing of helicopter rotors is given extensive treatment, and the author suggests ways in which wind tunnels can be used in non-aeronautical capacities.

The worked examples and problems, which were such a valuable feature of the first edition, have been brought up to date, and the production of the whole book is still excellent.—E.C.P.

Additions to the Library

A.N.C. CRITERIA FOR STANDARD INSTRUMENT APPROACH PROCEDURES. U.S.G.P.O. 1954.
Braddon, R. CHESHIRE **V.C.** EVANS BROS. 1954.
Cadambe, V. ENGINEERING RESEARCH IN INDIA. C.S.I.R. New Delhi. 1954.
Green, W. and G. Pollinger. THE WORLD'S FIGHTING PLANES. Macdonald. 1954.
Kemp, P. K., Lt. Cdr. FLEET AIR ARM. Jenkins. 1954.
Knight, S. A. FUNDAMENTALS OF RADAR (Second Edition). Pitman. 1954.
Langewiesche, W. A FLIER'S WORLD. Hodder & Stoughton. 1954.
Levens, A. S. GRAPHICS IN ENGINEERING AND SCIENCE. J. Wiley. (C. & H.) 1954.
Lithgow, M. MACH ONE. Allan Wingate. 1954.
Ludlam, F. H. and R. S. Scorer. FURTHER OUTLOOK. Wingate. 1954.
National Bureau of Standards. FORMULAS FOR COMPUTING CAPACITANCE AND INDUCTANCE. U.S.G.P.O. 1954.
Plantema, F. J. THEORY AND EXPERIMENTS ON THE ELASTIC OVERALL INSTABILITY OF FLAT SANDWICH PLATES. E. Ijdo-Leiden. 1952.
Templeton, H. MASSBALANCING OF AIRCRAFT CONTROL SURFACES. Aeronautical Monographs, Volume IV. C. & H. 1954.
Thetford, O. G. and E. J. Riding. AIRCRAFT OF THE 1914-18 WAR. Harleyford. 1954.
University of Minnesota, Inst. of Technology. PROCEEDINGS: THIRD MIDWESTERN CONFERENCE ON FLUID MECHANICS. University of Minnesota. 1953.
U.S. Dept. of Agriculture. HOW TO SPRAY THE AIRCRAFT WAY. U.S.G.P.O. 1954.
Veale, S. E. AIRCRAFT FOR ALL. Ward Lock. 1954.
*Wely, Dr. F. P. H. Prick van. KRAMERS DUTCH DICTIONARY (ENGLISH-DUTCH, DUTCH-ENGLISH), 17th Edition.

* Reference only.

Reports

AERODYNAMICS

Boundary Layer

Note on the results of some profile drag calculations for a particular body of revolution at supersonic speeds. J. R. Wedderspoon and A. D. Young. Cranfield Report No. 81 (*July* 1954).

Details additional to those discussed in College of Aeronautics Report No. 73 are given of the method developed for the calculation of the profile drag of bodies of revolution at supersonic speeds and zero incidence. The method has been applied to a particular body of fineness ratio 7·5 for Mach numbers ranging from 1·5 to 5·0, Reynolds numbers ranging from 10^6 to 10^9 and transition positions ranging from the nose to the tail end of the body. The calculations assume zero heat transfer.—(1.1.2.4).

*The effects of surface irregularities on transition in the laminar boundary layer. E. H. Cowled. A.R.L. Australia. Report A.*86 (*April* 1954).

It is possible by suitable choice of parameters to correlate for each type of irregularity, experimental results from various sources. The method presented permits the prediction of transition up to high flight Reynolds numbers and the assessment of the effect of multiple disturbances.—(1.1.2.1).

Compressible Flow

Equations, tables, and charts for compressible flow. Ames Research Staff. N.A.C.A. Report 1135 (1953).

This report, which is a revision and extension of TN 1428, presents a compilation of equations, tables, and charts useful in the analysis of high-speed flow of a compressible fluid. The equations provide relations for continuous one-dimensional flow, normal and oblique shock waves, and Prandtl-Meyer expansions for both perfect and imperfect gases. The tables present useful dimensionless ratios for continuous one-dimensional flow and for normal shock waves as functions of Mach number for air considered as a perfect gas. One series of charts presents the characteristics of the flow of air (considered a perfect gas) for oblique shock waves and for cones in a supersonic airstream. A second series shows the effects of caloric imperfections on continuous one-dimensional flow and on the flow through normal and oblique shock waves.—(1.2.3).

Transonic flow past cone cylinders. G. E. Solomon. N.A.C.A. Technical Note 3213 (*September* 1954).

Experimental results are presented for transonic flow past cone-cylinder, axially symmetric bodies. The drag coefficient and surface Mach number are studied as the free-stream Mach number is varied and, wherever possible, the experimental results are compared with theoretical predictions. Interferometric results for several typical flow configurations are shown and an example of shock-free supersonic-to-subsonic compression is experimentally demonstrated. The theoretical problem of transonic flow past finite cones is discussed briefly and an approximate solution of the axially symmetric transonic equations, valid for a semi-infinite cone, is presented.—(1.2.2).

Application of two-dimensional vortex theory to the prediction of flow fields behind wings of wing-body combinations at subsonic and supersonic speeds. A. W. Rogers. N.A.C.A. Technical Note 3227 (*September* 1954).

A theoretical method is evaluated for predicting flow fields behind wings of wing-body combinations at supersonic speeds and slender configurations at subsonic speeds. The method is applied to the calculation of downwash at tail locations behind wings of triangular-wing and cylindrical-body combinations at $M=2{\cdot}0$, to illustrate effects of aspect ratio, angle of attack and incidence, ratio of body radius to wing semispan, and angle of bank on the vortex wake.—(1.2.3.1 × 1.2.1.1).

Control Surfaces

High speed wind tunnel tests on vane type air brakes. A. S. Bennett and P. B. Atkins. A.R.L. Aerodynamics Note 136 (*July* 1954).

Two air brakes consisting of banks of turning vanes have been tested in the Variable Pressure tunnel on a model wing similar to a portion of a Vampire wing. Tests were also made on the clean wing and on the wing fitted with a flat plate dive brake. Force measurements and Schlieren observations were made at an incidence of approximately 0°.—(1.3.4).

Fluid Dynamics

Ueber die Umstromung zylindrischer Korper in einer geradlinigen Couettesstromung. H. Reichardt. Mitteilungen aus dem Max-Planck Institut fur Stromungsforchung. Göttingen. No. 9 (1954).—(1.4).

Performance Estimation

Water and air performance of seaplane hulls as affected by fairing and fineness ratio. A. G. Smith and J. E. Allen. R. & M. 2896 (*August* 1950, *published* 1954).

An analysis is made of data on the variation of hull air drag with length/beam ratio and degree of local fairing, and of the maximum beam loading permitted for reasonable hydrodynamic performance. The effect of length/beam ratio on hull structure weight is also very briefly discussed. Charts are given to help in the selection of the best hull form for any given design conditions. From these may be estimated dimensions, air drag, and the maximum beam loading to give a reasonable standard of water performance.—(1.7).

Stability and Control

A note on the dynamic stability of aircraft at high-subsonic speeds when considering unsteady flow. W. J. G. Pinsker. R. & M. 2904 (*May* 1950, *published* 1954).

The effect of an increase in speed relative to the speed of sound on the unsteady flow round a harmonically oscillating aerofoil, is to increase the lag of the aerodynamic forces and moments behind the deflection when the frequency is small. It is shown theoretically that this will result in a serious deterioration of the damping of both the lateral oscillation and the high frequency longitudinal oscillation with high Mach numbers. Use is made of derivatives calculated for flutter purposes to estimate the unsteady derivatives at aircraft oscillation frequencies. Illustrative examples are presented.—(1.8).

Systematisch-kritische Beispielrechnungen zur Seitenstabilität der Flugzeuge. H. Scharn. D.F.L. Inst. Flugmech. Bericht M 2/54.

The results of lateral stability calculations are obtained from applying the classical theory of lateral stability of aeroplanes with rudder fixed, to a number of types of aeroplanes. The calculations are based on the general equations of motion of a rigid body, moving freely through space under the effects of aerodynamic and gravitational forces. For describing the motion a system of principal axes of inertia, fixed to the body, is chosen, and the conditions of stability are investigated in accordance with the theory of oscillations of small amplitudes.—(1.8).

Die Koordinatensysteme der Flugmechanik. W. Schulz and R. Ludwig. D.F.L. Inst. Flugmech, Braunschweig Bericht M 3/54.

Tabulation of co-ordinate systems occurring in the flight analyses of aeroplanes is given with the rules relevant for transformation.—(1.8).

NOTE.—*The figures in parenthesis at the end of each Summary are for office use only.*

Über die Bewegungs- und Störungsgleichungen in einem flugzeugfesten Koordinatensystem. W. Schulz. D.F.L. Inst. Flugmech. Bericht M 4/54.

The equations for the motion of an aeroplane in space and the equations for the disturbances, as they are used for stability calculations, can be written down in a convenient way by the matrix form. Moreover a way is shown of applying the Laplace transformation to the equations for the disturbances.—(1.8).

Theoretical analysis of an airplane acceleration restrictor controlled by normal acceleration, pitching acceleration, and pitching velocity. C. C. Kraft. N.A.C.A. Technical Note 3243 (*September* 1954).

An acceleration restrictor which limits the elevator motion has been analysed. The system has been assumed to be sensitive to two different control signals. One signal is proportional to normal and pitching acceleration and the other is a function of normal and pitching acceleration and pitching velocity. Several values of time lag in the device used to stop the elevator motion have been studied for two centre of gravity positions and for forward speeds up to 1,000 feet per second.—(1.8.2 × 33.1.1).

THERMO-AERODYNAMICS

Heat transfer from a hemisphere-cylinder equipped with flow-separation spikes. J. R. Stalder and H. V. Nielsen. N.A.C.A. Technical Note 3287 (*September* 1954).

Average heat-transfer, temperature-recovery, and pressure-distribution measurements were obtained over the hemispherical nose of a body of revolution both with and without flow-separation spikes. The tests, conducted in a range of Reynolds numbers from 1·55 to $9{\cdot}85 \times 10^5$ and from Mach number 0·12 to 5·04, indicated that in supersonic flow the addition of spikes approximately doubles the rate of heat transfer, regardless of spike length.—(1.9.1).

Turbulent-heat-transfer measurements at a Mach number of 3·03. *M. J. Brevoort and B. Rashis. N.A.C.A. Technical Note* 3303 (*September* 1954).

A three-dimensional axially symmetric plug nozzle was used to obtain flat-plate data on turbulent-heat-transfer coefficients and recovery factors. The test results of this paper are for Mach number 3·03 and for a Reynolds number range of $5{\cdot}6 \times 10^6$ to $6{\cdot}5 \times 10^7$.—(1.9.1).

Exact solutions of laminar-boundary-layer equations with constant property values for porous wall with variable temperature. P. L. Donoughe and J. N. B. Livingood. N.A.C.A. Technical Note 3151 (*September* 1954).

Solutions were computed for a Prandtl number of 0·7 and a range of cooling-air flows, and pressure and wall temperature gradients. For each case, boundary layer thicknesses and heat-transfer and friction coefficients were also computed and tabulated.—(1.9.1).

WINGS AND AEROFOILS

The application of camber and twist to swept wings in incompressible flow. G. G. Brebner. A.R.C. Current Paper 171 (*March* 1952, *published* 1954).—(1.10).

A note on the boundary layer and stalling characteristics of aerofoils. D. D. Carrow. A.R.C. Current Paper 174 (*October* 1950, *published* 1954).

A qualitative explanation is suggested for the changes which occur in the stalling characteristics of aerofoils as the Reynolds number is increased. This explanation is based on the variation, with Reynolds number, in the state of the boundary layer along the upper surface at just below the stalling incidence.—(1.10.2.1).

The influence of thickness-chord ratio on supersonic derivatives for oscillating aerofoils. W. P. Jones. R. & M. 2679 (*September* 1947, *published* 1954).

By the use of Temple and Jahn's theory for the oscillating flat plate and Busemann's theory for aerofoils in steady motion, derivatives are obtained for symmetrical circular-arc and double-wedge aerofoils describing low frequency oscillations at supersonic speeds.—(1.10.1.1 × 2.0).

Swept wings in supersonic flight. S. B. Gates. R. & M. 2818 (*December* 1946, *published* 1954).

Ackeret's theory of two-dimensional wave reaction is here extended to include sweep. The formulae so derived are used to compare the performance of a straight wing with one swept through 45°, making some allowance for frictional drag.—(1.10.1.2).

Theoretical calculations of the distribution of aerodynamic loading on a delta wing. H. C. Garner. R. & M. 2819 (*March* 1949, *published* 1954).

The distribution of velocity potential difference has been calculated for a thin flat plate in the form of a delta wing at small incidence. The method introduces novel functions with 10 arbitrary constants to express the doublet distribution over the wing and a special numerical integration to evaluate the downwash at 10 chosen points on the surface. Three different forms of the doublet distribution are employed, leading to three independent solutions of the resulting simultaneous equations.—(1.10.1.2 × 1.6.1).

On the application of transonic similarity rules to wings of finite span. J. R. Spreiter. N.A.C.A. Report 1153 (1953).

The transonic aerodynamic characteristics of wings of finite span are discussed from the point of view of a unified small perturbation theory for subsonic, transonic, and supersonic flows about thin wings. The relation between the two methods of analysis of transonic flow is examined, the similarity rules and known solutions of transonic flow theory are reviewed, and the asymptotic behaviour of the lift, drag, and pitching-moment characteristics of wings of large and small aspect ratio is discussed.—(1.10.1.2).

Investigation of lift, drag, and pitching moment of a 60° *delta-wing-body combination (AGARD calibration model B) in the Langley* 9*-inch supersonic tunnel. A. F. Bromm. N.A.C.A. Technical Note* 3300 (*September* 1954).

Results are presented from tests of the AGARD Calibration Model B in the Langley 9-inch supersonic tunnel. Measurements were made of the lift, drag, and pitching moment at Mach numbers of 1·62, 1·94, and 2·41 and at a Reynolds number, based on body length, of approximately $3{\cdot}0 \times 10^6$.—(1.10.2.2).

HELICOPTER AERODYNAMICS

Helicopter control to trim in forward flight. W. Stewart. R. & M. 2733 (*March* 1950, *published* 1954).

A theoretical estimation of the flapping and feathering (cyclic pitch) to trim the helicopter rotor in forward flight is given and the equivalence of the two systems is shown. The feathering amplitudes to trim the complete helicopter are then estimated and compared with experimental flight values obtained on the Sikorsky R-4B and S-51 helicopters. The effects of centre of gravity position, fuselage pitching moment, and so on, are considered and the delta-3 hinge effect is dealt with in an appendix. The effect of slipstream curvature on lateral control is included.—(1.11.2).

TESTING AND INSTRUMENTS

Flight trials of a rocket-propelled transonic research model: The R.A.E.—Vickers rocket model. Parts I to IV. The Staff of the Supersonics Division, Flight Section, R.A.E. R. & M. 2835 (*March* 1950, *published* 1954).—(1.12.2).

Starting and operating limits of two supersonic wind tunnels utilizing auxiliary air injection downstream of the test section. H. R. Hunczak and M. D. Rousso. N.A.C.A. Technical Note 3262 (*September* 1954).

Data are presented for tunnels operating at Mach numbers 3·85, 3·05, and 2·87 over a range of injector-to-tunnel mass-flow ratios of 0·5 to 1·35. At Mach number 3·85, the starting pressure ratio of 9·8 without injectors but with a fixed second throat was reduced to 4·68 with injectors operating at an injector-to-tunnel mass flow ratio of 1·27. The running pressure ratio was lowered from 8·3 to 4·5.—(1.12.1.3).

AEROELASTICITY

See also AERODYNAMICS: WINGS AND AEROFOILS

Control-surface flutter with the stick free. H. Templeton. R. & M. 2824 (*May* 1950, *published* 1954).

A method of solution for the determination of the stick-free flutter characteristics of a control system when the inertia of the stick is allowed for is proposed which corresponds to impedance matching between circuit and control surface in the flutter condition. The method is applied, by way of illustration, to two typical cases, an elevator system and a servo-tab system, and the effect of variations in stick inertia and circuit stiffness demonstrated.—(2.0).

HYDRODYNAMICS

A proposed theory to cover water impacts of seaplanes in which the craft has constant attitude and a tangential-to-keel velocity relative to the water. P. R. Crewe. R. & M. 2513 (*December* 1946, *published* 1954).

Several important problems of impact and planing motion at constant attitude relative to the water, with finite tangential-to-keel velocity, may be connected by the supposition that 'impact-planing' forces occur in all of them and are simply related to the 'pure impact' forces of classical impact theory. Formulae for relevant equations of motion, based on these assumptions, are developed.—(17.2).

INSTRUMENTS AND EQUIPMENT

Determinacion del funcionamiento del conjunto neumatico-amortiguador. P. Cicala. Aeronautical Institute, Cordoba, Argentine. Communicaciones e Informes 1-2 (1954).—(18.2).

MATERIALS

Methods of testing reinforced plastics. Parts I and II. Part I Measurement of Tensile Strength. Part II Measurement of Interlaminar Strength. F. T. Barwell. R. & M. 2702 (*April* 1948, *published* 1954).

An experimental comparison has been made between five types of tensile tests including novel types designed to enable axial loading conditions to be approached more readily than is the case with established methods. Examination of the results of two hundred and forty tests indicates that significant differences can occur between the results of different tests and that there is also a significant variation between the properties of material cut from different parts of the same sheet.—(21.6.1).

Étude de la déformation et de la rupture des matières plastiques. F. Zandman. Publications Scientifiques et Techniques du Ministère de l'Air, France. No. 291 (1954).—(21).

STRUCTURES

LOADS

See also AERODYNAMICS: STABILITY AND CONTROL

On a minimum time flight path with regard to stress and heat limitations. H. Behrbohm. SAAB, Sweden. TN 26 (*February* 1954).

As an ideal limiting case for tactical considerations the extremal flight paths are determined which minimise the time to fly from a point A to point B in space under the following auxiliary conditions: measuring the load strain in terms of dynamic pressure q and the temperature strain in terms of Mach number M the flight shall be performed at q=const. up to a certain critical altitude H, but at M=const. above that altitude. This note gives a solution of the problem using H=11 km. and an exponential approximation of the air density-altitude law. The equations of the flight paths and the times required to fly along such paths can be given by very simple formulae. The practical applicability is discussed.—(33.1.1).

An experimental investigation of wheel spin-up drag loads. B. Milwitzky, D. C. Lindquist, and D. M. Potter. N.A.C.A. Technical Note 3246 (*September* 1954).

This paper presents some recently obtained information on landing-gear applied drag loads and on the nature of the wheel spin-up phenomenon in landing, based on a programme of tests under controlled conditions in the Langley impact basin. In particular, a study has been made of the nature and variation of the coefficient of friction between the tyre and the runway during the spin-up process. Also, comparisons have been made of the various results obtained in forward-speed impacts, forward-speed impacts with reverse wheel rotation, spin-up drop tests, and forward-speed impacts with wheel prerotation.—(33.1.2).

THEORY AND ANALYSIS

Stress concentrations at a cut-out in a swept wing. E. H. Mansfield. R. & M. 2823 (*July* 1951, *published* 1954).

The stress concentrations are determined for a panel, bounded by main load-carrying members and an oblique edge, such as might occur at a cut-out in a swept wing. The solutions given are exact and cover the effects of a member along the oblique edge and of closely-spaced stringers attached to the panel.—(33.2.3.2).

Stress distributions caused by three types of loading on a circular semimonocoque cylinder with flexible rings. H. G. McComb. N.A.C.A. Technical Note 3199 (*September* 1954).

Equations are derived for the stress distributions caused by three types of loading on infinitely long, circular, semimonocoque cylinders with flexible rings. The results are given as formulae for the stringer loads and shear flows in the shell due to each type of loading. For each loading case these formulae can be used to construct tables of influence coefficients giving stringer loads and shear flows in the neighbourhood of the load due to a unit magnitude of that load.—(33.2.4.3.0).

Stress analysis of circular semimonocoque cylinders with cut-outs by a perturbation load technique. H. G. McComb. N.A.C.A. Technical Note 3200 (*September* 1954).

A method is presented for analysing the stresses about a cutout in a circular cylinder of semimonocoque construction. The method involves the use of so-called perturbation solutions which are superposed on the stress distribution that would exist in the structure with no cutout in such a way as to give the effects of a cutout. The method can be used for any loading case for which the structure without the cutout can be analysed and is sufficiently versatile to account for stringer and shear reinforcement about the cutout.—(33.2.4.3).

Bending tests on box beams having solid- and open-construction webs. A. E. Johnson. N.A.C.A. Technical Note 3231 (*August* 1954).

The results of an exploratory experimental investigation of the effects of replacing alternate webs in a multiweb beam by open, post-stringer construction are reported. Post-stringer (either upright or inclined posts) construction is shown to perform the function of comparable-weight, solid, fabricated webs in the stabilisation of the compression cover of a beam in bending both before and after buckling.—(33.2.4.1.2).

An analysis of the stability and ultimate bending strength of multiweb beams with formed-channel webs. J. W. Semonian and R. A. Anderson. N.A.C.A. Technical Note 3232 (*August* 1954).

Design curves and procedures are presented for calculating the stresses at which wrinkling instability and failure occur in multiweb beams with formed-channel webs. The theory is compared with test data for multiweb beams in bending and a criterion is given for predicting whether a given beam will be susceptible to a wrinkling instability or will buckle in a local mode.—(33.2.4.1.2).

Additional static and fatigue tests of high-strength aluminum-alloy bolted joints. E. C. Hartmann, M. Holt and I. D. Eaton. N.A.C.A. Technical Note 3269 (*August* 1954).

Additional static and fatigue tests were made on a few types of joints in 75S-T6, 24S-T4, and 14S-T6 high-strength aluminium-alloy extruded bar in order to supplement the data in N.A.C.A. Technical Note 2276. Comparisons are made with the results of these earlier tests.—(33.2.4.13.10).

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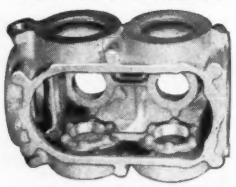

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The Journal of the Royal Aeronautical Society

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INDEX TO VOL LVIII January - December 1954

ACOUSTICS

Acoustics—Particularly Jet Engine Noise—A Discussion.
Aerodynamic Noise, G. M. Lilley, p. 235 (April).
Engine Noise, F. B. Greatrex, p. 223 (April).
Ground-to-Ground Noise, J. D. Hayhurst, p. 248 (April).
Jet Engine Noise, E. J. Richards, p. 221 (April).
Measurement of Noise on the Ground from Aircraft in Flight, N. Fleming, p. 245 (April).
Noise Associated with Supersonic Flight, C. H. E. Warren, p. 239 (April)
The Noise from Aircraft (T.N.), A. G. Walters, p. 65 (Jan.).

ADLER, R. B. and FRICKER, S. J.

Notes on the Flow of Scheduled Air Traffic, p. 475 (July).

ADMITTANCE

See Receptance.

AERODYNAMICS

See also Shock Tube.
A Possible Method for Obtaining High Mach Numbers using Compressed Air Supplies of Relative Low Pressures (T.N.), F. Van Der Walle, p. 510 (July).
A Proposal on the Electric Tank Method for Study of a Symmetrical Aerofoil with a Rear Suction Slot and a Retractable Flap (T.N.), Syogo Matsunaga, p. 434 (June).
Stability and Control in Aircraft Design, J. C. Wimpenny, p. 329 (May).
The Determination of Turbulent Skin Friction by means of Pitot Tubes, J. H. Preston, p. 109 (Feb.).
The Pressure Rise with Subsonic Mach Number on Fuselages and Nacelles (T.N.), D. E. Hartley, p. 567 (Aug.).
The Reynolds Analogy Applied to a Cylinder Rotating in Air (T.N.), Y. R. Mayhew, p. 205 (March).

AEROELASTICITY

An Aspect of the Deformation of Swept Wings in Steady Supersonic Flight, B. A. Hunn and G. N. Lance, p. 754 (Nov.).
Recent Developments in the Structural Approach to Aeroelastic Problems, D. Williams, p. 403 (June).

AEROPLANES

Bristol—*See* Barnwell Memorial Lecture.
Supermarine—*See* Mitchell Memorial Lecture.

AIR INTAKE

See Engines.

AIR TRAFFIC CONTROL

See Air Transport.

AIR TRANSPORT

See also Instrument Approach, Meteorology, A. E. Russell.
Notes on the Flow of Scheduled Air Traffic, R. B. Adler and S. J. Fricker, p. 475 (July).
Practical Experience of Airline Engineering, R. C. Morgan, p. 585 (Sept.).
Terminal Delay Problems of the 130/150 Seater Jet Transport (T.N.), William Courtenay, p. 208 (March).

AIRCRAFT INDUSTRY

Where Goes the Aircraft Industry, Sir Walter Puckey, p. 769 (Nov.).

AIRWORTHINESS

The Arithmetic of Airworthiness, Walter Tye, p. 195 (March).

ALDRIDGE, P. J.

The Development of an Early Helicopter, p. 556 (Aug.).

ANNAND, W. J.

Heat Transfer Equations for an Air-Air Heat Exchanger (T.N.), p. 783 (Nov.).

ANNUAL REPORT

See Royal Aeronautical Society.

ASQUITH, K. and WHITAKER, J. G.

Definition of Specific Impulse (T.N.), p. 370 (May), p. 728 (Oct.).

BARNWELL, F. S., MEMORIAL LECTURE, THE FIRST

Captain F. S. Barnwell, Major G. P. Bulman, p. 381 (June).

BILLING, B. F.

A Null Method for the Measurement of Load in Axial Fatigue Testing Machines (T.N.), p. 508 (July).

BIOT, M. A., DUNCAN, W. J., JOHNSON, D. C., BISHOP, R. E. D.

Receptances in Mechanical Systems (T.N.), p. 305 (April).

BISHOP, R. E. D.

The Analysis and Synthesis of Vibrating Systems, p. 703 (Oct.).

BISHOP, R. E. D., DUNCAN, W. J., BIOT, M. A., JOHNSON, D. C.

Receptances in Mechanical Systems (T.N.), p. 305 (April).

BLERIOT, LOUIS—SEVENTH LECTURE

The Domain of the Helicopter, Raoul Hafner, p. 661 (Oct.).

BRETT, P. and GARDINER, G. C. I.

Propellers for High-Speed Aircraft, p. 799 (Dec.).

BULMAN, MAJOR G. P.

Captain F. S. Barnwell, p. 381 (June).

BUSK STUDENTSHIP

P. 560 (Aug.).

CANADIAN AERONAUTICAL INSTITUTE

P. XLI (Aug.), p. XXXV (July), p. 779 (Nov.)

CAREY, F. H.

The Development of the Spill Flow Burner and Its Control System for Gas Turbine Engines, p. 737 (Nov.).

CATCHPOLE, E. J.

The Optimum Design of Compression Surfaces Having Unflanged Integral Stiffeners, p. 765 (Nov.).

CHAMBERS, E.

Meteorological Services for the Comet, p. 173 (March).

CHATTERTON, E. E.

Compound Diesel Engines for Aircraft, p. 613 (Sept.).

CHILVER, A. H.

The Estimation of Fatigue Damage in Aircraft Wing Structures, p. 396 (June).

COMPRESSOR BLADES

See also Eddy Velocity, Flutter and Vibration, Glass Cloth/Resin.
Some Blade Designs for an Axial Flow Compressor Stage (T.N.), R. G. Taylor, p. 61 (Jan.).

COUNCIL REPORT

See Royal Aeronautical Society.

COURTENAY, WILLIAM

Terminal Delay Problems of the 130/150 Seater Jet Transport (T.N.), p. 208 (March).

COX, H. L.

Computation of Initial Buckling Stress for Sheet-Stiffener Combinations, p. 634 (Sept.).

COX, HUGH L.

Flexural Vibration of Plates on Uniform Elastic Foundations (T.N.), p. 651 (Sept.).

CUTLER, A. E. and RINGHAM, G. B.

Flight Simulators, p. 153 (March).

DATA SHEETS, ROYAL AERONAUTICAL SOCIETY

See Catchpole, E. J., p. 765 (Nov.), Cox, H. L., p. 634 (Sept.), Yusuff, S., p. 808 (Dec.).

DESIGN AND CONSTRUCTION

See also Gliding.
Integral Construction—A Survey and an Experiment, K. L. C. Legg, p. 485 (July).
Stability and Control in Aircraft Design, J. C. Wimpenny, p. 329 (May).

DUNCAN, W. J.
Stability Criteria, with Special Reference to the Sextic Equation (T.N.), p. 431 (June).
Stability Criteria for the Octic Equation (T.N.), p. 649 (Sept.).

DUNCAN, W. J., BIOT, M. A., JOHNSON, D. C., BISHOP, R. E. D.
Receptances in Mechanical Systems (T.N.), p. 305 (April).

EDDY VELOCITY
Relative Eddy and its Effects on the Performance of a Radial Bladed Centrifugal Impeller, K. R. Reddy, p. 547 (Aug.).

ELECTRIC TANK
See Aerodynamics.

ELECTRONIC COMPUTING
See Williams, D.

EMINTON, E., ROUTLEDGE, N. A., LORD, W. T.
Note on the Evaluation of an Integral (T.N.), p. 787 (Nov.).

ENGINES
See also Compressor Blades.
Air Intake Efficiency, F. B. Greatrex, p. 639 (Sept.).
Compound Diesel Engines for Aircraft, E. E. Chatterton, p. 613 (Sept.).
Effects of Fuel Type on the Performance of Aero Gas Turbine Combustion Chambers, and the Influence of Design Features, J. G. Sharp, p. 813 (Dec.).
The Choice of Power Units for Civil Aeroplanes (The 42nd Wilbur Wright Memorial Lecture), A. E. Russell, p. 521 (Aug.).
The Development of the Spill Flow Burner and Its Control System for Gas Turbine Engines, F. H. Carey, p. 737 (Nov.).

EQUATIONS, SOLUTION OF
Stability Criteria, with Special Reference to the Sextic Equation (T.N.), W. J. Duncan, p. 431 (June).
Stability Criteria for the Octic Equation (T.N.), W. J. Duncan, p. 649 (Sept.).

FARREN, SIR WILLIAM
From the President, p. III (Jan.).

FATIGUE
See also Instruments.
A Method for Determining the "Safe" Life of an Aircraft Wing from Fatigue Test Results, A. P. Kennedy, p. 361 (May).
A Photoelastic-Fatigue Programme of Experimental Research in Connection with Bolted Joints, E. W. C. Wilkins and H. T. Jessop, p. 435 (June).
The Estimation of Fatigue Damage in Aircraft Wing Structures, A. H. Chilver, p. 396 (June).
The Level of Safety Achieved by Periodic Inspection for Fatigue Cracks (T.N.), R. R. Shaw, p. 720 (Oct.).

FEDDEN, SIR ROY
H. P. Folland—An Appreciation, p. 833 (Dec.).

FERRIER, AIR VICE-MARSHAL A.
The Canadian Aeronautical Institute, p. 779 (Nov.).

FIFTIETH ANNIVERSARY POWERED CONTROLLED FLIGHT DINNER
P. 128 (Feb.)

FLEMING, N.
Measurement of Noise on the Ground from Aircraft in Flight, p. 245 (April).

FLIGHT SIMULATORS
Flight Simulators, G. B. Ringham and A. E. Cutler, p. 153 (March).

FLUTTER AND VIBRATION
Cascade Blade Flutter and Wake Excitation (T.N.), J. F. W. Parry and H. Pearson, p. 505 (July).

FOLLAND, H. P.—AN APPRECIATION
Sir Roy Fedden, p. 833 (Dec.).

FORREST, G.
Internal or Residual Stresses in Wrought Aluminium Alloys and their Structural Significance, p. 261 (April).

FRICKER, S. J. and ADLER, R. B.
Notes on the Flow of Scheduled Air Traffic, p. 475 (July).

FUELS AND OILS
See Engines and Lubrication.

GARDEN PARTY 1954
P. 562 (Aug.).

GARDINER, G. C. I. and BRETT, P.
Propellers for High-Speed Aircraft, p. 799 (Dec.).

GLASS CLOTH/RESIN
The Manufacture of Glass Cloth/Resin Blades for an Axial Flow Compressor, J. H. Horlock, p. 434 (June).
The Use of Glass Cloth/Resin Moulded Components in the Laboratory (T.N.), F. G. Irving and R. A. Saunders, p. 139 (Feb.).

GLIDING
Progress in Sailplane Design, K. G. Wilkinson, p. 456 (July).
Recent Progress in Gliding, A. H. Yates, p. 447 (July).
The Performance Testing of the Slingsby Sky, K. E. Machin, p. 470 (July).

GOODEY, W. J.
Note on the Derivation of the Natural Modes and Frequencies of a Structure by the Method of Minimum Strain Energy (T.N.), p. 573 (Aug.).

GREATREX, F. B.
Air Intake Efficiency, p. 639 (Sept.).
Engine Noise, p. 223 (April).

GREENWOOD, S. W.
Definition of Specific Impulse (T.N.), p. 728 (Oct.).
Correction to previous Note, p. 143 (Feb.).

GUNSTONE, G. L.
The Comparison of a "Wake Brake" and a Parachute for the Landing of Aeroplanes (T.N.), p. 372 (May).

GUSTS
Gusts and Their Measurement, J. Taylor, p. 826 (Dec.).

HAFNER, RAOUL
The Domain of the Helicopter—Seventh Louis Bleriot Lecture, p. 661 (Oct.).

HARTLEY, D. E.
The Pressure Rise with Subsonic Mach Number on Fuselages and Nacelles (T.N.), p. 567 (Aug.).

HAYHURST, J. D.
Ground-to-Ground Noise, p. 248 (April).

HEAT EXCHANGER
Heat Transfer Equations for an Air-Air Heat Exchanger (T.N.), W. J. Annand, p. 783 (Nov.).

HELICOPTERS
The Development of an Early Helicopter, P. J. Aldridge, p. 556 (Aug.).
The Domain of the Helicopter—Seventh Louis Bleriot Lecture, Raoul Hafner, p. 661 (Oct.)
The Flight Envelope of a Helicopter (T.N.), P. R. Payne, p. 785 (Nov.).

HENSHALL, B. D.
The Shock Tube—A Versatile Tool of Aerodynamic Research, p. 541 (Aug.).

HEUGHAN, D. M.
Note on the Comparison of a "Wake Brake" and a Parachute for the Landing of Aeroplanes (T.N.), p. 201 (Mar.). p. 372 (May).

HOFF, N. J.
Buckling and Stability — Forty-First Wilbur Wright Memorial Lecture, p. 3 (Jan.).

HORLOCK, J. H.
The Manufacture of Glass Cloth/Resin Blades for an Axial Flow Compressor, p. 434 (June).

HOWARD, H. B.
Tubes of Optimum Bending Stiffness: An Analogy (T.N.), p. 296 (April).

HUNN, B. A. and LANCE, G. N.
An Aspect of the Deformation of Swept Wings in Steady Supersonic Flight, p. 754 (Nov.).

HYDRAULIC SYSTEMS
The Development of 4,000 lb./in.² Hydraulic Systems, G. Orloff, p. 185 (March).

INSTRUMENT APPROACH
A Quantitative Study of Instrument Approach, J. F. W. Mercer, p. 83 (Feb.).

INSTRUMENTS
A Null Method for the Measurement of Load in Axial Fatigue Testing Machines (T.N.), B. F. Billing, p. 508 (July).

INTEGRAL CONSTRUCTION
See Design and Construction and Structures.

INTEGRAL, EVALUATION OF AN
Note on the Evaluation of an Integral (T.N.), N. A. Routledge, W. T. Lord and E. Eminton, p. 787 (Nov.).

INTEGRAL STIFFENERS
See Structures.

IRVING, F. G. and SAUNDERS, R. A.
The Use of Glass Cloth/Resin Moulded Components in the Laboratory (T.N.), p. 139 (Feb.).

JACKSON, S. B.
The Comparison of a "Wake Brake" and a Parachute for the Landing of Aeroplanes (T.N.), p. 371 (May).

JESSOP, H. T. and WILKINS, E. W. C.
A Photoelastic—Fatigue Programme of Experimental Research in Connection with Bolted Joints, p. 435 (June).

JOHNSON, D. C., DUNCAN, W. J., BIOT, M. A., BISHOP, R. E. D.
Receptances in Mechanical Systems (T.N.), p. 305 (April).

JOURNAL PREMIUM AWARDS
See Royal Aeronautical Society.

KENNEDY, A. P.
A Method for Determining the "Safe" Life of an Aircraft Wing From Fatigue Test Results, p. 361 (May).

KETTLE, D. J.
The Design of Static and Pitot Static Tubes for Subsonic Speeds (T.N.), p. 835 (Dec.).

KOITER, W. T.
The Flexural Centre or Centre of Shear (T.N.), p. 64 (Jan.).

KRZYWOBLOCKI, M. Z. v.
Stress Analysis of Circular Frames, p. 438 (June) (Addition to Technical Note, p. 600, Sept. 1953).

LANCE, G. N. and HUNN, B. A.
An Aspect of the Deformation of Swept Wings in Steady Supersonic Flight, p. 754 (Nov.).

LANDING RUN
Note on the Comparison of a "Wake Brake" and a Parachute for the Landing of Aeroplanes (T.N.), D. M. Heughan, p. 201 (March); S. B. Jackson, G. L. Gunstone, D. M. Heughan, p. 371 (May).

LEAKAGE RATES
See Pressurisation.

LECTURES
See also Barnwell, Bleriot, Mitchell *and* Wilbur Wright.

Branch Lectures:
Meteorological Services for the Comet, E. Chambers (Brough), p. 173 (March).
The Development of an Early Helicopter, P. J. Aldridge (Bristol), p. 556 (Aug.).
Where Goes the Aircraft Industry, Sir Walter Puckey (Bristol), p. 769 (Nov.).

Main Lectures:
Aeronautical Acoustics—A Discussion, p. 221 (April).
A Quantitative Study of Instrument Approach, J. F. W. Mercer, p. 83 (Feb.).
Compound Diesel Engines for Aircraft, E. E. Chatterton, p. 613 (Sept.).
Flight Simulators, G. B. Ringham and A. E. Cutler (Belfast), p. 153 (March).
Practical Experience of Airline Engineering, R. C. Morgan (Chester), p. 585 (Sept.).
Recent Developments in the Structural Approach to Aeroelastic Problems, D. Williams, p. 403 (June).
Stability and Control in Aircraft Design, J. C. Wimpenny, p. 329 (May).

Section Lectures:
Air Intake Efficiency, F. B. Greatrex, p. 639 (Sept.).
Gusts and Their Measurement, J. Taylor, p. 826 (Dec.).
Integral Construction—A Survey and an Experiment, K. L. C. Legg, p. 485 (July).
Progress in Sailplane Design, K. G. Wilkinson, p. 456 (July).
Propellers for High-Speed Aircraft, G. C. I. Gardiner and P. Brett, p. 799 (Dec.).
Recent Progress in Gliding, A. H. Yates, p. 447 (July).
The Development of 4,000 lb./in.² Hydraulic Systems, G. Orloff, p. 185 (March).
The Development of the Spill Flow Burner and its Control System for Gas Turbine Engines, F. H. Carey, p. 737 (Nov.).

LECTURE SPEAKERS
See Royal Aeronautical Society.

LEGG, K. L. C.
Integral Construction—A Survey and an Experiment, p. 485 (July).

LILLEY, G. M.
Aerodynamic Noise, p. 235 (April).

LINER, H. S.
The Natural Frequencies and Modes of Vibration of a Rotating Beam (T.N.), p. 652 (Sept.).

LORD, W. T., ROUTLEDGE, N. A., EMINTON, E.
Note on the Evaluation of an Integral (T.N.), p. 787 (Nov.).

LUBRICATION
Foaming and Aeration of Oils in Aviation Power Plant, R. Tourret, p. 53 (Jan.).

MACHIN, K. E.
The Performance Testing of the Slingsby Sky, p. 470 (July).

MACMILLAN, F. A.
Viscous Effects on Pitot Tubes at Low Speeds (T.N.), p. 570 (Aug.).
Viscous Effects on Flattened Pitot Tubes at Low Speeds (T.N.), p. 837 (Dec.).

MATERIALS
See also Glass Cloth/Resin.
Internal or Residual Stresses in Wrought Aluminium Alloys and their Structural Significance, G. Forrest, p. 261 (April).

MATSUNAGA, SYOGO
A Proposal on the Electric Tank Method for Study of a Symmetrical Aerofoil with a Rear Suction Slot and a Retractable Flap (T.N.), p. 434 (June).

MAYHEW, Y. R.
The Reynolds Analogy Applied to a Cylinder Rotating in Air (T.N.), p. 205 (March).

MCQUILLIN, L. A. and WHITEHEAD, L. G.
The Centre of Shear for Sections Bounded by Two Circular Arcs (T.N.), p. 138 (Feb.).

MEDALS AND AWARDS
See Royal Aeronautical Society.

MEDALS AND PRIZES FOR PAPERS
See Royal Aeronautical Society.

MERCER, J. F. W.
A Quantitative Study of Instrument Approach, p. 83 (Feb.).

METEOROLOGY
Meteorological Services for the Comet, E. Chambers, p. 173 (March).

MITCHELL MEMORIAL LECTURE
R. J. Mitchell—Aircraft Designer, J. Smith, p. 311 (May).

MOMENT DISTRIBUTION
See Structures.

MORGAN, R. C.
Practical Experience of Airline Engineering, p. 585 (Sept.).

NASH COLLECTION OF VETERAN AIRCRAFT
See Garden Party, 1954, p. 563 (Aug.).

NEW ZEALAND DIVISION
Fifth Annual Report, p. 429 (June).

NICHOLLS, A. C.
Empirical Formulae for the Determination of Stress Curves (T.N.), p. 724 (Oct.).

NOISE
See Acoustics.

ORLOFF, G.
The Development of 4,000 lb./in.^{2} Hydraulic Systems, p. 185 (March).

PARACHUTE BRAKING
See Landing Run.

PARRY, J. F. W. and PEARSON, H.
Cascade Blade Flutter and Wake Excitation (T.N.), p. 505 (July).

PAYNE, P. R.
A Method of Rapidly Estimating Propeller Moment (T.N.), p. 299 (April), Correction, p. 840 (Dec.).
The Flight Envelope of a Helicopter (T.N.), p. 785 (Nov.).

PEARSON, H. and PARRY, J. F. W.
Cascade Blade Flutter and Wake Excitation (T.N.), p. 505 (July).

PERFORMANCE
See Gliding.

PHOTOELASTICITY
A Photoelastic-Fatigue Programme of Experimental Research in Connection with Bolted Joints, E. W. C. Wilkins and H. T. Jessop, p. 435 (June).

PILOTING
See Flight Simulators.

PITOT TUBES
See also Aerodynamics.
Viscous Effects on Pitot Tubes at Low Speeds (T.N.), F. A. Macmillan, p. 570 (Aug.).
Viscous Effects on Flattened Pitot Tubes at Low Speeds (T.N.), F. A. Macmillan, p. 837 (Dec.).
The Design of Static and Pitot Static Tubes for Subsonic Speeds (T.N.), D. J. Kettle, p. 835 (Dec.).

PRESSURISATION
Leakage Rates From Pressurised Aircraft at Altitude (T.N.), H. J. Staite, p. 574 (Aug.).

PRESTON, J. H.
The Determination of Turbulent Skin Friction by Means of Pitot Tubes, p. 109 (Feb.).

PRICE, E. W.
Definition of Specific Impulse (T.N.), p. 839 (Dec.).

PRODUCTION
See Puckey, Sir Walter.

PROPELLERS
A Method of Rapidly Estimating Propeller Moment (T.N.), P. R. Payne, p. 299 (April), Correction, p. 840 (Dec.).
Propellers for High-Speed Aircraft, G. C. I. Gardiner and P. Brett, p. 799 (Dec.).

PUCKEY, SIR WALTER
Where Goes the Aircraft Industry, p. 769 (Nov.).

RECEPTANCE
Receptances in Mechanical Systems (T.N.), W. J. Duncan, M. A. Biot, D. C. Johnson, R. E. D. Bishop, p. 305 (April).

REDDY, K. R.
Relative Eddy and its Effects on the Performance of a Radial Bladed Centrifugal Impeller, p. 547 (Aug.).

REVIEWS
Advances in Applied Mechanics, Vol. III, edited by R. von Mises and Th. von Kármán, p. 73 (Jan.).
Adventure of Space Travel, The, G. V. E. Thompson, p. 211 (March).
Aerodynamics, Th. von Kármán, p. 841 (Dec.).
Aerodynamics of Propulsion, D. Küchemann and J. Weber, p. 376 (May).
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Aircraft for All, S. E. Veale, p. 848 (Dec.).
Aircraft of the World, The, William Green and Gerald Pollinger, p. 374 (May).
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Amazing Mr. Doolittle, The, Quentin Reynolds, p. 731 (Oct.).
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Analysis of Deformation, Vol. I, K. Swainger, p. 792 (Nov.).
Applied Elasticity, Chi-teh Wang, p. 513 (July).
Applied Thermodynamics, William Robinson and John M. Dickson, p. 581 (Aug.).
Atomic Energy, A Survey, edited by J. Rotblat, p. 439 (June).
Atomisation of Liquid Fuels, The, Prof. E. Giffen and Dr. A. Muraszew, p. 146 (Feb.).
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Axialkompressoren und Radialkompressoren, B. Eckert, p. 655 (Sept.).
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Book of Flight, The, Kenneth M. King, p. 657 (Sept.).
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Characteristics and Applications of Resistance Strain Gauges, National Bureau of Standards, p. 731 (Oct.).
Collected Papers of Stephen P. Timoshenko, The, p. 515 (July).
Communication Theory, edited by Willis Jackson, p. 74 (Jan.).
Complete Air Navigator, The, D. C. T. Bennett, p. 374 (May).
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Cover of Darkness, Roderick Chisholm, p. 75 (Jan.).
Development of the Guided Missile, Kenneth W. Gatland (2nd Ed.), p. 846 (Dec.).
Die Eroberung des Luftreiches, Peter Supf, p. 730 (Oct.).
Dimensional Methods and Their Applications, C. M. Focken, p. 376 (May).
Dimensioning of Engineering Drawings, The, W. Abbott, p. 146 (Feb.).
Dynamics and Thermodynamics of Compressible Fluid Flow, The, Ascher H. Shapiro, Vol. I, p. 375 (May); Vol. II, p. 846 (Dec.).
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Elasticity, Plasticity and Structure of Matter, R. Houwink, p. 579 (Aug.).
Electrical Ignition Equipment, F. G. Spreadbury, p. 845 (Dec.).
Electronics, T. B. Brown, p. 729 (Oct.).
Energy Transfer in Hot Gases, National Bureau of Standards, p. 657 (Sept.).
Engineering Steels, Leslie Aitchison and William Pumphrey, p. 306 (April).
Engineering Units and the Stroud Convention, F. W. Thorne and A. C. Walshaw, p. 846 (Dec.).
Ernst Heinkel "Stürmisches Leben," edited by Jürgen Thorwald, p. 580 (Aug.).
Faster Than Thought, edited by B. V. Bowden, p. 213 (March).
Fatigue and Fracture of Metals, edited by Murray and Hunsaker, p. 75 (Jan.).
Feathered Wings, Anthony Jack, p. 147 (Feb.).

First Through the Clouds, F. Warren Merriam, p. 373 (May).
Fleet Air Arm, Lt.-Cdr. P. K. Kemp, p. 844 (Dec.).
Fliegen in Unserer Zeit, C. Walther Vogelsang, p. 514 (July).
Flight Handbook (5th Ed.), p. 848 (Dec.).
Flight Into Space, Jonathan Norton Leonard, p. 211 (March).
Fundamentals of Radar, Stephen A. Knight (2nd Ed.), p. 847 (Dec.).
Funfstellige Tafel der Trigonometrischen Funktionem, p. 732 (Oct.).
Fünfzig Jahre Motorflug, edited by Dr. Franz Bunda, p. 514 (July).
Gauge Making and Measuring, National Physical Laboratory, p. 847 (Dec.).
Gasdynamik, K. Oswatitsch, p. 74 (Jan.).
Gas Turbine Analysis and Practice, Burgess H. Jennings and Willard L. Rogers, p. 72 (Jan.).
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Green and Red Planet, The, Hubertus Srughold, p. 75 (Jan.).
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Helicopter and How It Flies, The, John S. Fay, p. 789 (Nov.).
Helicopter Operation and Design Requirements, p. 791 (Nov.).
High Altitude Rocket Research, Dr. Homer E. Newell, Jr., p. 579 (Aug.).
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Higher Transcendental Functions, Vols. I and II, Based on Notes by Professor Harry Bateman and compiled by Bateman Manuscript Project, p. 732 (Oct.).
Hydraulic Systems and Equipment, R. Hadekel, p. 729 (Oct.).
Ideas and Weapons, I. B. Holley, Jr., p. 793 (Nov.).
Instrument Engineering, Vol. II, C. S. Draper, W. McKay, S. Lees, p. 442 (June).
Intermediate Engineering Drawing, A. C. Parkinson, p. 516 (July).
Introduction to Aeronautical Dynamics, Manfred Rauscher, p. 373 (May).
Introduction to Dynamics, L. A. Paro, p. 211 (March).
Introduction to Liquid Propellant Rocket Engineering, An, D. A. Parish, p. 307 (April).
Introduction to Relaxation Methods, An, F. S. Shaw, p. 213 (March).
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Jusqu'au Bout Sur Nos Messerschmitt, Général Galland, p. 845 (Dec.).
L'Aviation des Origines à Nos Jours, General Hebrard, p. 793 (Nov.).
Letter Symbols, Signs and Abbreviations, Part I: General, British Standards Institution, p. 792 (Nov.).
Lubricant Testing, E. G. Ellis, p. 145 (Feb.).
Mach One, "Mike" Lithgow, p. 844 (Dec.).
Man in Space, Heinz Haber, p. 211 (March).
Man on the Moon, edited by Cornelius Ryan, p. 211 (March).
Materials and Processes (2nd Ed.), James F. Young, p. 732 (Oct.).
Mathematics in Action, O. G. Sutton, p. 578 (Aug.).
Mechanical Vibration, G. W. Yan Santen, p. 306 (April).
Mémoires sur la Mécanique des Fluides, D. P. Riabouchinsky, p. 842 (Dec.).
Methods of Mathematical Physics, Vol. I, R. Courant and D. Hilbert, p. 514 (July).
Microscopical Techniques in Metallurgy, H. Thompson, p. 581 (Aug.).
Model Jets and Rockets for Boys, Raymond Yates, p. 793 (Nov.).
Modern Developments in Fluid Dynamics—High Speed Flow, p. 144 (Feb.).
Neville Duke's Book of Flying, Edited by Edward Lanchbery, p. 849 (Dec.).
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No Distress Signals, Winifred Brown, p. 847 (Dec.).
Observer's Book of Aircraft, The, William Green and Gerald Pollinger, p. 75 (Jan.).
Petroleum and Performance, E. M. Goodger, p. 145 (Feb.).
Physics of the Stratosphere, The, R. M. Goody, p. 442 (June).
Pioneer of the Air: The Life and Times of Colonel S. F. Cody, G. A. Broomfield, p. 656 (Sept.).
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Quest for a Northern Air Route, Alexander Forbes, p. 374 (May).
Reach for the Sky, Paul Brickhill, p. 513 (July).
Rendez-Vous 127. Diary of Mme. Brusselmans, p. 848 (Dec.).
Royal Air Force, 1939-1945, Vol. I—The Fight at Odds, Dennis Richards, p. 440 (June).
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Royal Air Force, The, 1939-1945, Vol. III: The Fight is Won, Hilary St. George Saunders, p. 847 (Dec.).
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Shape of the Aeroplane, The, James Hay Stevens, p. 441 (June).
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Slide Rule, Nevil Shute, p. 790 (Nov.).
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Sound Barrier, Neville Duke and Edward Lanchbery (6th Ed.), 6. 849 (Dec.).
Space Travel, Kenneth Gatland and Anthony M. Kunesch, p. 211 (March).
Statically Indeterminate Structures, Professor Chu-Kia Wang, p. 73 (Jan.).
Statistical Theory of Extreme Values and Some Practical Applications, Emil J. Gumbel, p. 792 (Nov.).
Statistics for Technologists, C. G. Paradine and B. H. P. Rivett, p. 144 (Feb.).
Strategy for the West, Sir John Slessor, p. 843 (Dec.).
Stress Concentration Design Factors, R. E. Peterson, p. 790 (Nov.).
Student and Private Pilot's Handbook, H. H. Edwards, p. 148 (Feb.).
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Textbook of the Materials of Engineering, Herbert F. Moore and Mark B. Moore, p. 376 (May).
Theoretical Elasticity, A. E. Green and W. Zerna, p. 844 (Dec.).
Theory and Design of Steam and Gas Turbines, John F. Lee, p. 729 (Oct.).
Theory of Machines, B. B. Low, p. 513 (July).
Thermodynamics and Statistical Mechanics, William P. Allis and Melvin A. Herlin, p. 73 (Jan.).
Thermodynamics Applied to Heat Engines, E. H. Lewitt, p. 75 (Jan.).
"Tiger" Squadron, Ira Jones, p. 849 (Dec.).
Time Enough to Live, D. Brennan, p. 847 (Dec.).
Titanium and Titanium Alloys, John L. Everhart, p. 843 (Dec.).
To Perish Never, Henry Archer and Edward Pine, p. 848 (Dec.).
Transactions of the Symposium on Fluid Mechanics and Computing, p. 657 (Sept.).
Ultra High Frequency Propagation, Henry R. Reed and Carl M. Russell, p. 306 (April).
V2, Major-General Walter Dornberger, p. 731 (Oct.).
View From The Air, Hugh Fosburgh, p. 847 (Dec.).
Victory on Wings—Wilbur and Orville Wright Taught Us How To Fly, Henri Hegener, p. 656 (Sept.).
Winged Life, The: A Portrait of Antoine de Saint-Exupéry,

Poet and Airman, Richard Rumbold and Lady Margaret Stewart, p. 147 (Feb.).
X-Ray Diffraction Patterns of Lead Compounds, p. 656 (Sept.).

RICHARDS, E. J.
Jet Engine Noise, p. 221 (April).

RINGHAM, G. B. and CUTLER, A. E.
Flight Simulators, p. 153 (March).

ROUTLEDGE, N. A., LORD, W. T., EMINTON, E.
Note on the Evaluation of an Integral (T.N.), p. 787 (Nov.).

ROYAL AERONAUTICAL SOCIETY
Acknowledgments, pp. VI (Jan.), IX (Feb.), XVI (March), XXIII (April), XXVIII (May), XXXVIII (July), LIV (Nov.), LIX (Dec.).
Additions to the Library, pp. 76, 148, 214, 307, 377, 442, 516, 581, 657, 732, 793, 849.
Annual Report of the Council, 1953-54, p. 277 (April).
Annual Subscriptions, pp. IV (Jan.), LVI (Nov.).
Associate Fellowship Examination Results, pp. XII (Feb.), XLII (Aug.).
Australian Division, Melbourne Branch, p. XLI (Aug.).
Balance Sheets, p. 286 (April).
Branches and Divisions, pp. II (Jan.), XIII (March), XX (April), XXVI (May), XL (Aug.), XLVIII (Oct.), LVIII (Dec.).
Busk Studentship in Aeronautics, p. 560 (Aug.).
Canadian Aeronautical Institute, p. XLI (Aug.), p. 779 (Nov.).
Committees of Council, p. 278 (April).
Council, 1954-1955, pp. XXXIV (July), LII (Nov.).
Election of Vice-Presidents, p. XXXVII (July).
Elections, pp. VI, XII, XVIII, XXIV, XXVIII, XXXII, XXXVIII, XLII, XLVI, XLIX, LVI, LXI.
Elliott Memorial Prize, pp. XXII (April), XLI (Aug.), LXI (Dec.).
Fiftieth Anniversary of Powered Controlled Flight—Dinner, p. 128 (Feb.).
From the President—Sir William S. Farren, p. III (Jan.).
Garden Party, 1954, p. 562 (Aug.).
Honours Awarded to Members, pp. IX (Feb.), XVIII (March), XXXVII (July), XLIX (Oct.), LXI (Dec.).
Journal Binding, pp. XII (Feb.), LXI (Dec.).
Journal Premium Awards, p. XXIII (April).

Lectures
See main heading for Main Society, Section and Branch Lectures and Special Lectures published in 1954.

Lecture Speakers
Adams, H. T., p. 631 (Sept.); Alcock, J. F., p. 628 (Sept.); Banks, Air Commodore F. R., p. 628, p. 630 (Sept.); Bateman, E. H., p. 426 (June); Baxter, A. D., p. 232 (April); Bell, G. E., p. 250, p. 257 (April); Boothman, Air Marshal Sir John N., p. 326 (May); Bressey, Capt., p. 103 (Feb.); Briscoe, John, p. 251 (April); Broadbent, E. G., p. 423 (June); Brown, D. G., p. 243 (April); Bulman, Major G. P., p. 327 (May); Calvert, E. S., p. 101 (Feb.); Camm, Sir Sydney, p. 630 (Sept.); Campbell-Orde, A. C., p. 233 (April); Caplan, H., p. 256 (April); Carlisle, E. L., p. 630 (Sept.); Cave-Browne-Cave, T. R., p. 252 (April); Chatterton, E. E., p. 633 (Sept.); Coleridge, T. T. N., p. 631 (Sept.); Collar, A. R., p. 349 (May); Cundall, H. B., p. 609 (Sept.); Cutler, A. E., p. 171 (March); Davies, Handel, p. 243 (April), p. 348 (May); Davies, S. D., p. 605 (Sept.); Doetsch, K., p. 351 (May); Dryburgh, W. W., p. 231 (April); Duncan, W. J., p. 425 (June); Dunn, W. H., p. 631 (Sept.); Eales, B., p. 233 (April); Edwards, G. R., p. 424 (June); Ettinger, G. M., p. 254 (April); Evans, R. N., p. 255 (April); Farren, Sir William, p. 101 (Feb.), p. 326 (May), p. 395 (June), p. 605, p. 611 (Sept.); Fleming N., p. 232, p. 253, p. 258, p. 260 (April); Frise, L. G., p. 394 (June); Gardner, H. H., p. 423 (June); Giddings, H., p. 258 (April); Gould, Major J. R., p. 630 (Sept.); Greatrex, F. B., p. 235, p. 241, p. 260 (April); Haines, A. B., p. 354 (May); Hardman, J. M., p. 350 (May); Hayhurst, J. D., p. 248, p. 255, p. 257 (April); Hislop, G. S., p. 257 (April); King, A. J., p. 251, p. 254, p. 255 (April); King, J. C., p. 171 (March); Laight, B. P., p. 607 (Sept.); Lawson, K. S., p. 352 (May); Lee, G. H., p. 349 (May); Lilley, G. M., p. 232, p. 244, p. 258 p. 259 (April); Livesley, R. K., p. 425 (June); Lloyd Thomas, E., p. 170 (March); Mercer, J. F. W., p. 108 (Feb.); Meredith, F. W., p. 351 (May); Morgan, R. C., p. 610 (Sept.); Moult, E. S., p. 629 (Sept.); Neilson, C. B. V., p. 609 (Sept.); Neumark, S., p. 422 (June); Oram, J. F. M., p. 253 (April); Pike, E. W., p. 103 (Feb.); Pinsker, W., p. 353 (May); Powell, Alan, p. 242, p. 259 (April); Pritchard, H. C., p. 103 (Feb.); Radcliffe, A., p. 231 (April); Reader, T. D., p. 233, p. 253, p. 260 (April); Rendell, D., p. 233, p. 252 (April); Richards, E. J., p. 234, p. 250, p. 256, p. 258 (April); Richardson, E. G., p. 242, p. 257 (April); Ringham, G. B., p. 171 (March); Rowe, N. E., p. 107 (Feb.), *see* Errata, p. XVIII (March), p. 608 (Sept.); Roxbee Cox, Sir Harold, p. 423 (June); Saunders, —., p. 233 (April); Sawyer, W. J. A., p. 233, p. 252 (April); Shenstone, B. S., p. 607, p. 630 (Sept.); Shevloff, N. P., p. 426 (June); Skellon, W., p. 609 (Sept.); Slatter, B. H., p. 608 (Sept.); Smaill, A. J., p. 609 (Sept.); Sorley, Air Marshal Sir Ralph, p. 326 (May); Stallibrass, G. W., p. 106 (Feb.); Stepan, A., p. 232, p. 253 (April); Taylor, A. S., p. 354 (May), p. 424 (June); Thomas, H. H. B. M., p. 352 (May); Thornycroft, O., p. 259 (April); Tinson, C. W., p. 394 (June); Uwins, C. F., p. 393 (June); Vessey, H. F., p. 350 (May); Walker, P. B., p. 421 (June); Walters, I. F. B., p. 107 (Feb.); Warren, C. H. E., p. 244, p. 256 (April); Williams, D., p. 426 (June); Wimpenny, J. C., p. 353 (May); Woodward-Nutt, A. E., p. 255 (April); Yates, A. H., p. 241 (April).
Medals and Awards, Presentation of, pp. 1 (Jan.), 521 (Aug.).
Medals and Prizes for Papers, p. XXIII (April).
New Zealand Division, Fourth Annual Report, p. 429 (June).
Reports, pp. 77, 149, 215, 308, 378, 443, 517, 582, 658, 733, 794, 850.
Representatives on Other Bodies, p. XXI (April).
S.B.A.C. Educational Grants, p. XLIX (Oct.).
Selection of President-Elect, p. LIV (Nov.).
Secretary's News Letter, pp. XV (March), XXXV (July), LIII (Nov.).

RUSSELL, A. E.
The 42nd Wilbur Wright Memorial Lecture.—The Choice of Power Units for Civil Aeroplanes, p. 521 (Aug.).

SAILPLANES
See Gliding.

SAMSON, DEREK R.
The Analysis of Shear Distribution for Multi-Cell Beams in Flexure by Means of Successive Numerical Approximations, p. 122 (Feb.).

SAUNDERS, C. G.
Wind Tunnel Balance Design—The Simultaneous Measurement of Forces and Moments (T.N.), p. 141 (Feb.).

SAUNDERS, R. A. and IRVING, F. G.
The Use of Glass Cloth/Resin Moulded Components in the Laboratory (T.N.), p. 139 (Feb.).

SCHWALBE, W. L.
The Flexural Centre or Centre of Shear (T.N.), p. 728 (Oct.). (*Incorrectly credited to J. A. Jacobs—see* correction, p. 840 (Dec.).

SHARP, J. G.
Effects of Fuel Type on the Performance of Aero Gas Turbine Combustion Chambers, and the Influence of Design Features, p. 813 (Dec.).

SHAW, R. K.
The Level of Safety Achieved by Periodic Inspection for Fatigue Cracks (T.N.), p. 720 (Oct.).

SHEAR CENTRE
See Structures.

SHOCK TUBE
The Shock Tube—A Versatile Tool of Aerodynamic Research, B. D. Henshall, p. 541 (Aug.).

SKIN FRICTION
See Aerodynamics.

SMITH, J.
R. J. Mitchell—Aircraft Designer, p. 311 (May).

SOLVEY, J.
Some Notes on the Torsion-Bending Constant (T.N.), p. 367 (May).

SPECIFIC IMPULSE
Definition of Specific Impulse (T.N.), F. W. Thorne, p. 143 (Feb.); K. Asquith and J. G. Whitaker, p. 370 (May), S. W. Greenwood, K. Asquith and J. G. Whitaker, F. W. Thorne, p. 728 (Oct.); E. W. Price, p. 839 (Dec.).

SRINATH, L. S.
A Method of Moment Distribution by Graphical Analysis (T.N.), p. 302 (April).

STABILITY CRITERIA
See Equations, Solution of.

STAITE, H. J.
Leakage Rates From Pressurised Aircraft at Altitude (T.N.), P. 574 (Aug.)

STRESS CURVES
Empirical Formulae for the Determination of Stress Curves (T.N.), A. C. Nicholls, p. 724 (Oct.)

STRUCTURES
See also Stress Curves.
The Analysis and Synthesis of Vibrating Systems, R. E. D. Bishop, p. 703 (Oct.)
The Analysis of Shear Distribution for Multi-Cell Beams in Flexure by means of Successive Numerical Approximations, Derek R. Samson, p. 122 (Feb.)
Buckling and Stability (Forty-First Wilbur Wright Memorial Lecture), N. J. Hoff, p. 1 (Jan.)
The Centre of Shear for Sections Bounded by Two Circular Arcs (T.N.), L. G. Whitehead and L. A. Mcquillin, p. 138 (Feb.)
Computation of Initial Buckling Stress for Sheet-Stiffener Combinations, H. L. Cox, p. 634 (Sept.).
The Flexural Centre or Centre of Shear (T.N.), W. T. Koiter, p. 64 (Jan.).
The Flexural Centre or Centre of Shear (T.N.), W. L. Schwalbe (*not J. A. Jacobs*), p. 728 (Oct.), *See* Correction, p. 840 (Dec.).
Flexural Vibration of Plates on Uniform Elastic Foundations (T.N.), Hugh L. Cox, p. 651 (Sept.).
A Method of Moment Distribution by Graphical Analysis (T.N.), L. S. Srinath, p. 302 (April).
The Natural Frequencies and Modes of Vibration of a Rotating Beam (T.N.), H. S. Liner, p. 652 (Sept.).
Note on the Derivation of the Natural Modes and Frequencies of a Structure by the Method of Minimum Strain Energy (T.N.), W. J. Goodey, p. 573 (Aug.).
The Optimum Design of Compression Surfaces Having Unflanged Integral Stiffeners, E. J. Catchpole, p. 765 (Nov.).
Primary Instability of a Panel of Integral Construction with Unflanged Stiffeners, Syed Yusuff, p. 808 (Dec.).
Recent Developments in the Structural Approach to Aeroelastic Problems, D. Williams, p. 403 (June).
Some Notes on the Torsion-Bending Constant (T.N.), J. Solvey, p. 367 (May).
Stress Analysis of Circular Frames, M. Z. v. Krzywoblocki, p. 438 (June).
Tubes of Optimum Bending Stiffness: An Analogy (T.N.), H. B. Howard, p. 296 (April).

TAYLOR, J.
Gusts and Their Measurement, p. 826 (Dec.).

TAYLOR, R. G.
Some Blade Designs for an Axial Flow Compressor Stage (T.N.), p. 61 (Jan.).

THORNE, F. W.
Definition of Specific Impulse (T.N.), p. 143 (Feb.), p. 728 (Oct.).

TOURRET, R.
Foaming and Aeration of Oils in Aviation Power Plant, p. 53 (Jan.).

TYE, WALTER
The Arithmetic of Airworthiness, p. 195 (March).

VAN DER WALLE, F.
A Possible Method for Obtaining High Mach Numbers using Compressed Air Supplies of Relative Low Pressures (T.N.), p. 510 (July).

WAKE BRAKE
See Landing Run.

WALTERS, A. G.
The Noise from Aircraft (T.N.), p. 65 (Jan.).

WARREN, C. H. E.
Noise Associated with Supersonic Flight, p. 239 (April).

WHITAKER, J. G. and ASQUITH, K.
Definition of Specific Impulse (T.N.), p. 370 (May), p. 728 (Oct.).

WHITEHEAD, L. G. and MCQUILLIN, L. A.
The Centre of Shear for Sections Bounded by Two Circular Arcs (T.N.), p. 138 (Feb.).

WILBUR WRIGHT MEMORIAL LECTURE, FORTY-FIRST
Buckling and Stability, N. J. Hoff, p. 1 (Jan.).

WILBUR WRIGHT MEMORIAL LECTURE, FORTY-SECOND
The Choice of Power Units for Civil Aeroplanes, A. E. Russell, p. 521 (Aug.).

WILKINS, E. W. C. and JESSOP, H. T.
A Photoelastic-Fatigue Programme of Experimental Research in Connection with Bolted Joints, p. 435 (June).

WILKINSON, K. G.
Progress in Sailplane Design, p. 456 (July).

WILLIAMS, D.
Recent Developments in the Structural Approach to Aeroelastic Problems, p. 403 (June).
See also W. J. Goodey, p. 573 (Aug.).

WIMPENNY, J. C.
Stability and Control in Aircraft Design, p. 329 (May).

WIND TUNNEL
Wind Tunnel Balance Design—The Simultaneous Measurement of Forces and Moments (T.N.), C. G. Saunders, p. 141 (Feb.).

YATES, A. H.
Recent Progress in Gliding, p. 447 (July).

YUSUFF, SYED
Primary Instability of a Panel of Integral Construction with Unflanged Stiffeners, p. 808 (Dec.).

THE AERONAUTICAL QUARTERLY

A Journal devoted to Aeronautics and the Allied Sciences

Volume V NOVEMBER 1954 Part 4

CONTENTS

The Frequency of Failures within a Group of Similar Structures — *A. H. Chilver*

The Effect of Delta Vanes on Supersonic Wings — *M. A. Gorgui*

Estimation of the Effects of Distortion on the Longitudinal Stability of Swept Wing Aircraft at High Speeds — *B. S. Campion*

Index to Volume V

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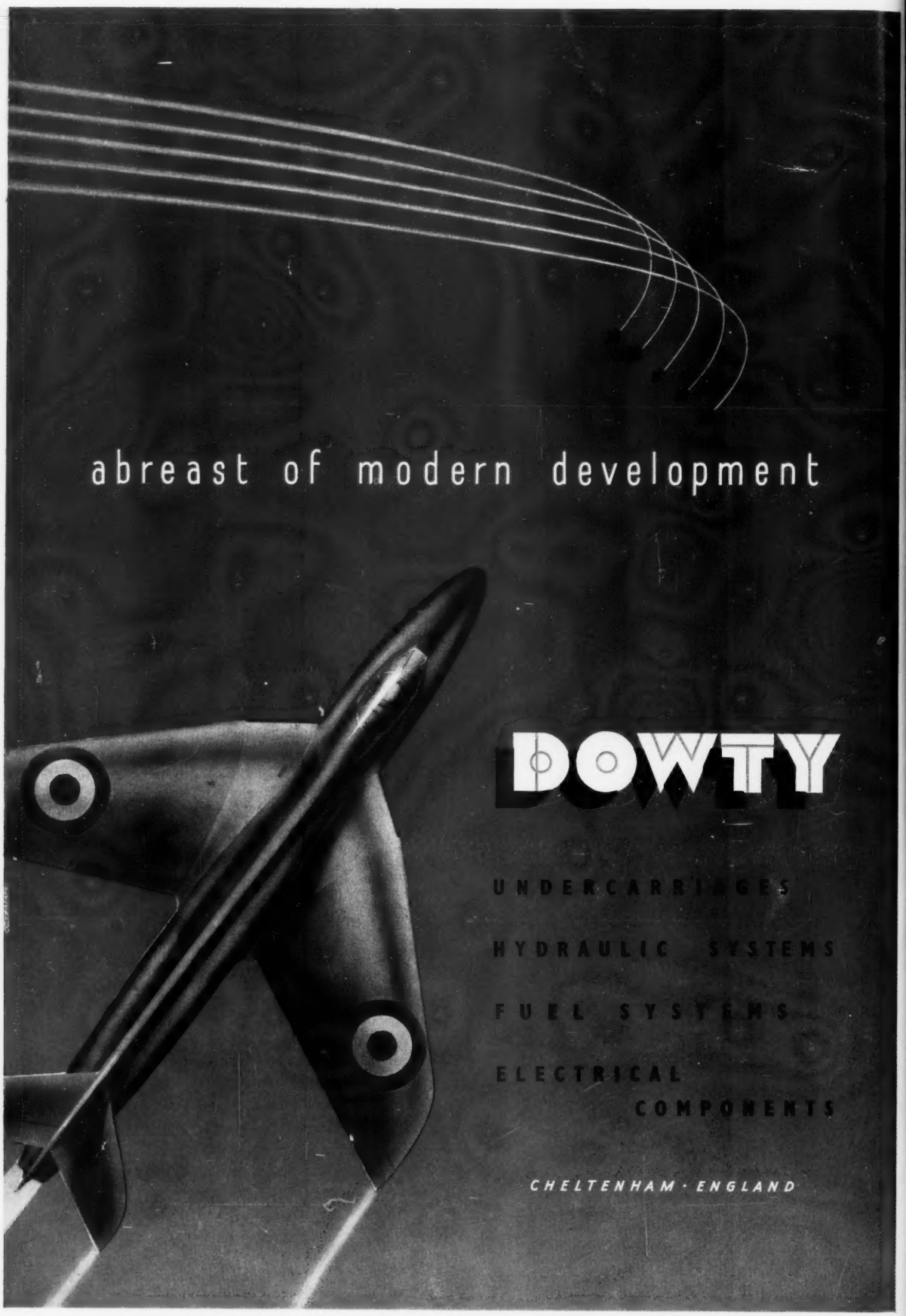

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